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Transmission media and optical systems characteristics – Optical fibre cables

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Test methods for installed single-mode fibre cable sections

ITU-T Recommendation G.650.3

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ITU-T Recommendation G.650.3

Test methods for installed single-mode fibre cable sections

Summary

ITU-T Recommendation G.650.3 outlines the tests normally done for installed optical cable sections. It includes a collection of references to the main measurement methods and gives an indication of which are most suitable for installed cable sections, depending on the required inspection level needed.

This Recommendation uses a tiered approach. The first level indicates measurements that may normally be done as part of installation. The second level indicates measurements that are normally done on exception, such as to satisfy service level agreements or to verify attributes of older links that may be used at high bit rates.

Source

ITU-T Recommendation G.650.3 was approved on 29 July 2007 by ITU-T Study Group 15 (2005-2008) under the ITU-T Recommendation A.8 procedure.

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.

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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.

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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ITU-T Recommendation G.650.3

Test methods for installed single-mode fibre cable sections

1 Scope

This Recommendation contains test methods which are particularly suited to the characterization of single-mode optical fibre cable sections. The methods are not intended for application to sections that contain optical network elements, amplifiers, dispersion compensators or passive splitters/combiners. Measurements associated with these devices, in combination with optical fibre cable, are defined elsewhere. These measurements of the cabling between such devices and the calculation methods for combining the results of concatenated cable sections are also presented.

This Recommendation uses a tiered approach. The first level indicates measurements that may normally be done as part of installation. The second level indicates measurements that are normally done on exception, such as to satisfy service level agreements or to verify attributes of older links that may be used at high bit rates.

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

[ITU-T G.650.2] ITU-T Recommendation G.650.2 (2007), *Definitions and test methods for statistical and non-linear related attributes of single-mode fibre and cable*.

[ITU-T G.671] ITU-T Recommendation G.671 (2005), *Transmission characteristics of optical components and subsystems*.

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

[IEC 61281-1] IEC 61281-1 (1999), *Fibre optic communication subsystems – Part 1: Generic specification*.

[IEC 61300-3-6] IEC 61300-3-6 (2005), *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-6: Examination and measurements – Return loss*.

[IEC/TR 61931] IEC/TR 61931 (1998), *Fibre optic – Terminology*.

3 Terms and definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 differential group delay (DGD): Defined in [ITU-T G.650.2].

3.1.2 fibre optical cable plant (FOCP): Defined in [IEC 61281-1].

3.1.3 fusion splice: Defined in [IEC/TR 61931].

3.1.4 mechanical splice: Defined in [IEC/TR 61931].

3.1.5 optical connector: Defined in [IEC 61281-1].

3.1.6 optical device: Defined in [IEC 61281-1].

3.1.7 optical return loss (ORL): Defined in [IEC 61281-1].

3.1.8 optical splice: Defined in [IEC/TR 61931].

3.1.9 polarization mode dispersion (PMD): Defined in [ITU-T G.650.2].

3.1.10 reflectance: Defined in [ITU-T G.671].

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 attenuation of fibre cable sections: The attenuation of fibre cable sections is the summation of the attenuations of fibre cable sections, splices between cable sections and connectors between cable sections. The definition of attenuation is defined in [ITU-T G.650.1]. Some examples of link attenuation measurement results are found in [b-ITU-T G.sup.39].

3.2.2 chromatic dispersion of fibre cable section: The overall chromatic dispersion of the cable section is the summation of the chromatic dispersions of the individual cables that comprise the section at the wavelength of interest. See [b-ITU-T G.sup.39] for more information on how the dispersions from different cable sections are summed up.

3.2.3 single-mode fibre cable section: A single (un-jointed) optical fibre cable. This is defined in [IEC 61281-1]. The differences between cable sections, cable plants and cable links can also be found in this IEC document.

3.2.4 uniformity of fibre link: The uniformity of a fibre link is defined as a longitudinal variation in the attenuation coefficient and/or chromatic dispersion coefficient.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

CWDM	Coarse Wavelength Division Multiplexing
DGD	Differential Group Delay
DWDM	Dense Wavelength Division Multiplexing
FFS	For Further Study
GINTY	Generalized INTerferometrY
OCWR	Optical Continuous-Wave Reflectometer
OTDR	Optical Time Domain Reflectometer
PMD	Polarization Mode Dispersion
RMS	Root Mean Square
SLA	Service Level Agreement
TINTY	Traditional INTerferometrY

5 Test methods

5.1 Test methods for characteristics of fibre cable sections following installation

The following characteristics of the fibre cable sections are commonly tested, though not required for performance verification. See clause 5.2 for additional testing that may be required for service contract requirements or for higher (10 Gbit/s per channel) transmission rates. [b-ITU-T G.sup.40] is a guide on the relationships and definitions of various attributes and measurement methods found in ITU and the mapping to the IEC version.

5.1.1 Attenuation, splice loss, splice location, fibre uniformity and length of cable sections

For these characteristics, the measurement method described in [ITU-T G.650.1] (the backscattering technique) is highly recommended. The instrument used for this measuring technique is called optical time domain reflectometer (OTDR). An OTDR is an instrument able to measure the optical power backscattered along a fibre as a function of distance. The detailed measurement technique is described in clause 5.4.2 of [ITU-T G.650.1]. The test apparatus and measurement procedure are described in clauses 5.4.2.2 and 5.4.2.3 of [ITU-T G.650.1].

If OTDR is used for overall attenuation checking of the cable sections, unidirectional OTDR test results can be used as a reference. If more careful evaluation of non-uniformities must be investigated, bidirectional OTDR test result needs to be considered as a judgement.

In practical engineering, unidirectional OTDR test results can be used to roughly judge the splice quality, as for the accurate splice loss measurement, it must be based on the bidirectional OTDR test. A formula of calculation of splice loss is as following:

$$Splice\ loss = \frac{\alpha_{A-B} + \alpha_{B-A}}{2} \qquad (5\text{-}1)$$

Where:

α_{A-B} is the shown (not real) splice loss test from A-end to B-end of cable sections

α_{B-A} is the shown (not real) splice loss test from B-end to A-end of cable sections

NOTE – OTDR can be used to test cable attenuation with length of approximately 80 kilometres, as for a concatenated cable section, the total attenuation can be derived directly as the sum of the attenuations of individual cable sections splices and connectors if they are included.

5.1.2 PMD

For transmission rates lower than 10 Gbit/s and/or short distance transmission, measurement of the PMD of cable sections may not be required. Either the interferometric method or a Stokes parameter method (fast Jones matrix eigenanalysis, JME) should be used. The interferometric method is described in detail in clause 5.1.3 of [ITU-T G.650.2]. The general introduction of this test method is described in clause 5.1.3.1 of [ITU-T G.650.2]. The Stokes parameter method is described in clause 5.1.1 of [ITU-T G.650.2] with details on JME given in clause 5.1.1.4.1 of [ITU-T G.650.2]. [b-IEC 61280-4-4] also provides a detailed description of the PMD measurement of links.

The main advantage of the interferometric method is that the measurement is very fast and the equipment can be easily used in the field. The dynamics and stability are provided by the well-established Fourier transform spectroscopy technique.

The Stokes parameter method is the reference test method, and some instruments based on JME have the speed and portability required for field use. This method has high accuracy, and is capable of measuring very low values of PMD.

The test apparatus of the interferometric method is described in clause 5.1.3.2 of [ITU-T G.650.2], the test procedures are regulated in 5.1.3.4 of [ITU-T G.650.2]. The traditional interferometry

(TINTY) procedures are described in clause 5.1.3.4.1 of [ITU-T G.650.2] and the generalized interferometry (GINTY) procedures are described in clause 5.1.3.4.2 of [ITU-T G.650.2].

The Stokes parameter test apparatus is given in clause 5.1.1.2 of [ITU-T G.650.2] and the procedure regulations are provided in clause 5.1.1.3 of [ITU-T G.650.2].

The above test methods can be used to test a limited length cable section. For a long cable section, the overall PMD can be calculated from the individual PMD values. The simple guidance on PMD calculation of optical cable sections is described in Appendix I. The detailed calculation method is described in [b-IEC 61282-3].

5.1.3 Chromatic dispersion

For chromatic dispersion, the phase-shift technique is used. This technique is described in clause 5.5.1 of [ITU-T G.650.1]. The test method can also be found in clauses 3.1 and A.1-A.3 of [b-IEC 60793-1-42].

Chromatic dispersion measurement is not essential for a low bit rate and/or short distance transmission.

NOTE – If the cable section is less than 40 km long to comprise an optical link used for 2.5 Gbit/s transmissions, the chromatic dispersion does not need to be tested. This measurement is conditional with respect to the planned bit rate.

5.1.4 Other parameters needed to be measured following installation

The sheath isolation and the pneumatic resistance of the joint boxes are sometimes tested. These characteristics are not directly related to the transmission performance of optical cable sections, but can affect the mechanical reliability. Standard tests for these parameters have not been developed.

5.2 Test methods for verification of service contracts or transmission at particular bit rates

The measurements listed below are normally carried out on an exceptional basis, e.g., for satisfying the requirements of service level agreements (SLA) or for qualifying links installed some time ago or for 10 Gbit/s transmission or above are listed.

5.2.1 Attenuation and related characteristics

For higher bit-rate transmission, the attenuation, splice loss, attenuation uniformity and section length after cable installation are also needed to be verified. The test methods for these characteristics are the backscattering technique as described in clause 5.1.1. The details of this test method are defined in clause 5.4.2 of [ITU-T G.650.1].

5.2.2 PMD

The test method of PMD of fibre cable sections is given in clause 5.1.3 of [ITU-T G.650.2]. The detailed description of the test method can be found in clause 5.1.3.4 of [ITU-T G.650.2].

The above test method can be used to test a limited length cable section. For a long cable section, the overall PMD can be calculated from the individual PMD values. The simple guidance on PMD calculation of optical cable sections is described in Appendix I. The detailed calculation method is described in [b-IEC 61282-3].

5.2.3 Chromatic dispersion

For chromatic dispersion requested in the wavelength region covered by the SLA (e.g., S-C-L band), the test method of this characteristic is given in clause 5.5.1 of [ITU-T G.650.1]: the phase-shift technique.

5.2.4 Optical return loss (ORL)

Two measurement methods for reflections of optical path (optical cable sections) are described in Appendix I of [ITU-T G.957]. One is with optical continuous-wave reflectometer (OCWR) and the other is with OTDR. For the purpose of reflectance and return loss measurements, points S_S and R_S are assumed to coincide with the endface of each connector plug. It is recognized that this does not include the actual reflection performance of the respective connectors in the operational system. These reflections are assumed to have the nominal value of reflection for the specific type of connectors used.

Four measurement methods are given in [IEC 61300-3-6].

Both OCWR and OTDR methods can be used to measure ORL of optical path (cable sections).

Appendix I

PMD calculations of concatenated cable sections

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

The calculation technique can be found in [b-IEC 61282-3]. Some guidance for the calculation of PMD in practical engineering will be described here.

The following text is derived from clause 3 of [b-IEC 61282-3]:

PMD is a stochastic attribute that varies in magnitude randomly over time and wavelength. The variation in the DGD value is described by a Maxwell probability density function that can be characterized by a single parameter, the PMD value. This parameter may be the average of the DGD values measured across a wavelength band, or it may be the rms value of these DGD values, depending on the definition chosen. For mode coupled fibre, the PMD coefficient is the PMD value divided by the square root of length.

PMD of cabled fibre should be specified/characterized on a statistical basis, not on an individual fibre basis. Two methods for this specification are proposed: method 1 can be used to obtain PMD_Q used in clause 2.2.1 of [b-IEC 61282-3] and method 2 can be used to obtain $DGDmax_F$ and P_F used in clause 2.2.2 of [b-IEC 61282-3]. The method and specification values chosen shall be agreed upon between the buyer and the cable manufacturer. Clause 3.3 of [b-IEC 61282-3] shows how specification values for each method can be selected so the two methods are nearly equivalent.

Method 1 relies on the fact that the mean PMD coefficient of an optical link is the root mean square (quadrature average) of the mean PMD coefficients of the cabled fibres comprising the link. Method 2 assumes the same relationship.

Let x_i and L_i be the PMD coefficient (ps/√km) and length, respectively, of a fibre in the i^{th} cable in a concatenated link of N cables. The PMD coefficient, x_N (ps/√km) of this link is:

$$x_N = \left[\frac{\sum_{i=1}^{N} L_i x_i^2}{\sum_{i=1}^{N} L_i} \right]^{1/2} = \left[\frac{1}{L_{Link}} \sum_{i=1}^{N} L_i x_i^2 \right]^{1/2} \qquad \text{(I-1)}$$

If one assumes that all cable section lengths are less than some common value, L_{Cab}, and simultaneously reducing the number of assumed cable sections to $M = L_{Link}/L_{Cab}$. Then, for a link comprised of equal-length cables, $L_i = L_{Cab}$, equation I-1 becomes:

$$x_N \le x_M = \left[\frac{L_{Cab}}{L_{Link}} \sum_{i=1}^{M} x_i^2 \right]^{1/2} = \left[\frac{1}{M} \sum_{i=1}^{M} x_i^2 \right]^{1/2} \qquad \text{(I-2)}$$

The variation in the concatenated link PMD coefficient, x_M, will be less than the variation in the individual cable sections, x_i, because of the averaging of the concatenated fibres.

Method 1 should be used with equation 1 of clause 2.2.1 of [b-IEC 61282-3]. In method 1, the manufacturer supplies a maximum PMD link design value, PMD_Q, that serves as a statistical upper bound for the PMD coefficient of the concatenated fibres comprising an optical cable link. For this case, the upper bound for the PMD value of the concatenation of optical fibre cables, PMD_{FTot}, in equation 1 of [b-IEC 61282-3] becomes:

$$PMD_{FTot} = PMD_Q \sqrt{L_{Link}} \qquad \text{(I-3)}$$

Unless otherwise specified in the detailed specification, the PMD link design value shall be less than 0.5 ps/√km, and the probability that a PMD coefficient of a link comprised of at least 20 cables will exceed the link design value shall be less than 10^{-4}. The link design value shall be computed using a method agreed upon between the buyer and cable manufacturer (see clause 3.1 of [b-IEC 61282-3] for examples).

Because method 1 provides a statistical upper bound on the PMD of concatenated links, approved PMD measurement methods can be used on installed cable links to determine whether their PMD complies with the statistical upper bound stated by the manufacturer. Furthermore, the upper bound can be used to compute the effect of the link PMD on the performance of any type of transmission system and is a more realistic indication of the maximum PMD likely to be encountered in a concatenated link than the value that would be obtained using a worst-case PMD value.

Method 2 should be used with equations 2 and 3 in clause 2.2.2 of [b-IEC 61282-3]. Method 2 combines the PMD density function of the concatenated links with the Maxwell probability density function of DGD values to compute an estimate of the probability that the DGD of a concatenated link at a given wavelength exceeds a specified value for a defined reference link.

The specification is that the probability that the DGD over the link exceeds a given value, $DGDmax_F$, shall be less than some maximum, P_F. One useful reference system consists of a concatenated link of 400 km comprised of forty 10 km cable sections. For such a link, the buyer and cable manufacturer may agree on specifying values such as $DGDmax_F$ = 25 ps for $P_F \leq 6.5 \times 10^{-8}$. The particular statistical methodology for their calculation shall be agreed between the buyer and cable manufacturer (see clause 3.2 of [b-IEC 61282-3]).

Appendix II

Measurement of the output Stokes vector rotation with time

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

This is under study.

Appendix III

Optical path parameters specified in ITU-T Recommendations

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

Specified parameters	**Related clause**	**G.691**	**G.692**	**G.693**	**G.695**	**G.696.1**	**G.698.1**	**G.959.1**
		STM-64 and other SDH	**Multi-channel**	**Intra-office**	**CWDM**	**Intra-domain DWDM**	**DWDM**	**OTN**
Attenuation (max/min)	5.1.1, 5.2.1	S	S	S	S	S	S	S
Chromatic dispersion (max/min)	5.1.3, 5.2.3	S	S	S	S	S/FFS	S	S
DGD (max)	5.1.2, 5.2.2	S	NS	S	S	S	S	S
Reflections (min ORL/ max discrete)	5.2.4	S	S	S	S	S	S	S

S Specified

NS Not specified

FFS For further study

NOTE – Minimum chromatic dispersion was not seen in [b-ITU-T G.691]. It is listed as "ffs" in [b-ITU-T G.696.1], but no frequency grids are defined.

Bibliography

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

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

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

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

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

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

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

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

[b-ITU-T G.Sup.40] ITU-T Supplement 40 to G-series Recommendations (2006), *Optical fibre and cable Recommendations and standards guideline*.

[b-IEC 60793-1-40] IEC 60793-1-40 (2001), *Optical fibres – Part 1-40: Measurement methods and test procedures – Attenuation*.

[b-IEC 60793-1-42] IEC 60793-1-42 (2007), *Optical fibres – Part 1-42: Measurement methods and test procedures – Chromatic dispersion*.

[b-IEC 61280-4-4] IEC 61280-4-4 (2006), *Fibre optic communication subsystem test procedures – Part 4-4: Cable plants and links – Polarization mode dispersion measurement for installed links*.

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

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