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APC

A SUPER HIGH CAPACITY SINGLE-MODE OPTICAL FIBRE FOR C+L WDM SYSTEM

Rev: 1.0 (2021)

Asian-Pacific Optical Fiber and
Cable Industry Association(APC)

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Introduction

This Recommendation describes the geometrical, transmissible, mechanical, and environment attributes of a super high capacity single-mode optical fibre (CL fibre) which is suitable for C+L band wavelength division multiplexing (WDM) communication system, which can effectively improve the available spectrum bandwidth to meet the demand of high speed and large capacity optical transmission.

According to the division of optical bands by ITU-T G.Sup39, the traditional C-band is 1530-1565nm, the L-band is 1565-1625nm, and the C+L band is 1530nm to 1625nm. However, the C+L band referred to in this Recommendation is 1520nm to 1625nm.

Keywords

Single-mode optical fibre, CL fibre, WDM communication system, super high capacity

Notes on previous revisions of this Recommendation

History edition	Recommendation No.	Release date	Study Group
V1.0	APC FAT-0001 V1.0 (2021)	December 01, 2021	APC Technical Development Committee

Contents

A super high capacity single-mode optical fibre for C+L WDM system

1 Scope

This Recommendation describes the attributes of a single-mode optical fibre for C+L band WDM system, referred to as CL fibre. The geometrical, transmissible, mechanical, and environmental parameters are presented below in five categories of attributes:

— The attenuation coefficients are limited at 1550nm and 1625nm, and the maximum values are specified;

— The FAWD (fibre attenuation coefficient warping degree) values in the two C+L bands, 1520nm and 1625nm, and the difference between the attenuation minima in the band, $\triangle\alpha_{1520}$ and $\triangle\alpha_{1625}$ are specified; (FAWDD) $\triangle\alpha$ (fibre attenuation warping degree difference) values are also determined.

— Other transmission parameters must be consistent with those of G.652D optical fibres;

— The coated optical fibres with diameters of 250μm and 200μm are specified by the geometrical parameters;

— The mechanical and environmental performance must be consistent with those of G.652D optical fibres;

2 Normative references

The following ITU-T Recommendations and other references constitute essential provisions of this Recommendation through normative references. Where, only the edition corresponding to the date is applicable to this Recommendation. Undated citations, the latest version of which (including all amendments) applies.

ITU-T Recommendation G.650.1 (2020), *Definitions and test methods for linear, deterministic attributes of single-mode fibre and cable*

ITU-T Recommendation G.650.2 (2015), *Definitions and test methods for statistical and non-linear related attributes of single-mode fibre and cable*

IEC/TR 62048 (2014), *The power-law theory of optical fibre reliability*

3 Terms and definitions

Relevant terms and definitions established in ITU-T G.650.1 and ITU-T G.650.2 apply to this Recommendation, as do those appearing below:

3.1.1 C+L single-mode optical fibre for WDM system (CL fibre)

A single-mode optical fibre for WDM systems with optimized attenuation performance supporting up to 240 waves in C+L bands.

3.1.2 Fibre attenuation coefficient warping degree (FAWD)

Within the specified wavelength range, when the attenuation coefficient is u-shaped with the wavelength, the difference between the attenuation coefficient at a particular wavelength and the minimum attenuation coefficient within the wavelength range is called the attenuation coefficient warping degree (FAWD). FAWD at 1520nm and 1625nm are represented by $\triangle\alpha_{1520}$ and $\triangle\alpha_{1625}$, respectively.

3.1.3 Fibre attenuation warping degree difference (FAWDD)

The warping degree difference, expressed by $\triangle\alpha$, is the absolute value of the arithmetic difference of the attenuation coefficient warping degree at two different specific wavelengths. Formula is:

$$\triangle\alpha = |\triangle\alpha_{1520} - \triangle\alpha_{1625}| \ldots\ldots\ldots\ldots\ldots (1)$$

4 Abbreviations

This Recommendation uses the following abbreviations:

WDM: Wavelength Division Multiplexing

FWM: Four Wave Mixing

PMD: Polarization Mode Dispersion

PMDQ: Link Polarization Mode Dispersion

FAWD: Fibre Attenuation coefficient Warping Degree

FAWDD: Fibre Attenuation Warping Degree Difference

5 Fibre attributes

5.1 Geometric parameters

The geometric parameters of CL optical fibre should comply with the provisions in Table 1

Table 1 - Geometric parameters of CL optical fibre

Attribute	Unit	Value	
		250μm	200μm
Cladding diameter	μm	125.0±0.7	125.0±0.7
Core concentricity error	μm	≤0.5	≤0.5
Cladding non-circularity	%	≤1.0	≤1.0
Coating layer diameter (uncolored)	μm	235～255	180～210
Coating layer diameter (colored)	μm	235～265	180～220
Cladding concentricity error	μm	≤12.5	≤10.0
Note - The geometric parameters of the fibre in the fibre ribbon can be more stringent.			

5.2 Transmission performance

5.2.1 Cut-off wavelength

The cut-off wavelength λc is temporarily set to be less than or equal to 1340nm, and the cut-off wavelength λcc after cable completion should be able to ensure single-mode transmission in C+L band.

5.2.2 Macrobending loss

The macrobending loss of CL fibre should comply with the provisions in Table 2.

The macrobending loss at 1625nm wavelength is selected as the indicator. Macrobending losses at other wavelengths can be agreed upon by the supplier and the user if necessary. Under the same bending radius, the maximum allowable macrobending loss should be proportional to the index in the table for the test with other bending turns.

Table 2 - The macrobending loss of CL fibre

Test condition		Unit	Value
Bending radius	30 mm	dB	0.1
Turns	100		
Wavelength	1625nm		

5.2.3 Attenuation coefficient

The attenuation coefficient of CL fibre should comply with the provisions in Table 3.

Table 3 - The attenuation coefficient of CL fibre

Attribute	Unit	Value		
		Level A	Level B	Level C
Maximum at 1550nm	dB/km	0.200		
Maximum at 1625nm		0.250		
$\Delta\alpha_{1520}$		≤0.020	≤0.018	≤0.015
$\Delta\alpha_{1625}$				
$\Delta\alpha$ absolute value		≤0.009	≤0.006	≤0.003

5.2.4 Chromatic dispersion

Within the wavelength region of 1260nm-1460nm, the limit value of dispersion coefficient D (λ) at any wavelength λ is calculated according to formula (1), (2) and (3).

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

$$\frac{\lambda S_{0\max}}{4}\left[1-\left(\frac{\lambda_{0\max}}{\lambda}\right)^4\right] \le D(\lambda) \le \frac{\lambda S_{0\max}}{4}\left[1-\left(\frac{\lambda_{0\min}}{\lambda}\right)^4\right] \quad (\lambda_{0\min} \le \lambda \le \lambda_{0\max}) \cdots\cdots (2)$$

$$\frac{\lambda S_{0\min}}{4}\left[1-\left(\frac{\lambda_{0\max}}{\lambda}\right)^4\right] \le D(\lambda) \le \frac{\lambda S_{0\max}}{4}\left[1-\left(\frac{\lambda_{0\min}}{\lambda}\right)^4\right] \quad (\lambda_{0\max} \le \lambda) \cdots\cdots (3)$$

where:
λ_{0max}——Maximum zero dispersion wavelength (nm)
λ_{0mim}——Minimum zero dispersion wavelength (nm)
S_{0max}——Maximum zero dispersion slope (ps/(nm2 ·km))
S_{0min}——Minimum zero dispersion slope (ps/(nm2 ·km))

$$8.625+0.052(\lambda-1460) \le D(\lambda) \le 12.472+0.068(\lambda-1460) \quad \cdots\cdots (4)$$

Within the wavelength region of 1460nm ~ 1625nm, the limit value of dispersion coefficient D (λ) at any wavelength λ is calculated according to formula (4)

The chromatic dispersion of CL fibre should comply with the provisions in Table 4.

Table 4 - The Chromatic dispersion of CL fibre

Attribute	Unit	Value
（λ_{0min}）[a]	nm	1300
（λ_{0max}）[a]	nm	1324
（S_{0min}）[a]	ps/(nm2 ·km)	0.073
（S_{0max}）[a]	ps/(nm2 ·km)	0.092
D_{min}（1550）[b]	ps/(nm ·km)	13.3
D_{max}（1550）[b]	ps/(nm ·km)	18.6
D_{min}（1625）[b]	ps/(nm ·km)	17.2
D_{max}（1625）[b]	ps/(nm ·km)	23.7
[a] 3-term Sellmeier fitting (1260nm-1460nm) [b] Linear fitting (1460nm-1625nm)		

The limit value of the dispersion coefficient D (λ) at any wavelength λ is calculated by formula (5)

$$D(\lambda)\leq\frac{\lambda S_{0MAX}}{4}\left[1-\left(\frac{\lambda_{0min}}{\lambda}\right)\right]^4 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5)}$$

where:

S_{0max}—Maximum zero dispersion slope (ps/(nm2 ·km))；

λ_{0mim}—Minimum zero dispersion wavelength (nm)；

5.2.5 Mode field diameter

The mode field diameter of CL fibre should comply with the provisions in Table 5.

Table 5 - The mode field diameter of CL fibre

Attribute	Unit	Value
1310nm	μm	8.6～9.2
Tolerance	μm	0.4

5.2.6 Intermittent attenuation

At 1310nm and 1550nm wavelengths, the point of discontinuity between the corresponding continuous length of the optical fibre should not exceed 0.1dB.

5.2.7 Attenuation uniformity

At 1310nm and 1550nm wavelengths, the regeneration section of the difference between the measured attenuation coefficient and the average attenuation coefficient of the whole length should not be greater than 0.05dB/km at any 2000m length of the backscattering signal.

5.2.8 Polarization mode dispersion coefficient

Only concatenated PMD coefficients are specified in this recommendation, and a maximum PMD_Q value should comply with the provisions in Table 6.

Table 6 - Maximum PMD coefficient of the link

Attribute		Unit	Value
PMD coefficient	M	ps/√km	20
	Q	ps/√km	0.01
	a maximum PMD_Q value on uncabled optical fibre link	ps/√km	0.20

5.3 Mechanical property

5.3.1 Tensile test

The mechanical strength tensile test requirements of CL fibre after coating should comply with the provisions of Table 7.

Table 7 - Tensile test requirements

Minimum proof stress	0.69 GPa
Minimum stress–strain	1.0%
Note - The proof stress value of 0.69 GPa is approximately equal to 1.0% strain or 8.8N tensile value. Please see IEC/TR 62048 for conversions between the three different units.	

If the bending radius is less than 30mm, the probability of fibre fracture increases with the decrease of the bending radius. The mechanical reliability is affected by cable structure, construction technology and routing conditions. Therefore, in the case of minimal bending applications, the tensile test grade or other influencing parameters can be appropriately increased to ensure the mechanical reliability and life requirements of the optical fibre.

The tensile test grade and the recommended mechanical reliability that can be achieved during the service life are determined by negotiation between the supplier and the user.

5.3.2 Tensile strength

The minimum tensile strength of an optical fibre before aging must meet the requirements listed in Table 8.

Table 8 - The minimum tensile strength before aging

Gauge length	Tensile strength when Weibull distribution is 15%	Tensile strength when Weibull distribution is 50%
0.5m	3.14 GPa	3.80 GPa
During the test, the gauge length of the fibre can be 10m or 20m. The longer the gauge length, the smaller the minimum tensile strength.		

5.3.3 Radius of curvature

The radius of curvature R of CL fibre should not be less than 4m.

5.3.4 Other mechanical properties

Other mechanical properties of CL fibre should comply with the provisions in Table 9.

Table 9 - Other mechanical properties of CL fibre

Attribute	Unit	Value	
		250 μm	200 μm
Peeling force of coating layer (mean)	N	1.0～5.0	0.4～5.0
Peeling force of coating layer (peak)	N	1.0～8.9	0.4～8.9
Dynamic fatigue parameter	n_d	≥20	
Note - The mean value or peak value of the peeling force of coating layer is defined during the test and can be agreed between the supplier and the user.			

5.4 Environmental performance

5.4.1 Overview

The environmental performance of CL fibre includes the change of light attenuation and mechanical properties after environmental test.

5.4.2 The variation of light attenuation after environmental test

The variation requirements of light attenuation after environmental tests shall conform to Table 10.

Table 10 - The variation requirements of light attenuation after environmental tests

Attribute	Detail	Wavelength nm	dB/km Allowable attenuation variation
Steady damp-heat	The relative humidity should not be less than 85%, set for 30 days	1550, 1625	≤0.05
Dry heat	The relative humidity is not higher than 50% at 35℃, set for 30 days	1550, 1625	≤0.05
Temperature	Temp. Range -60℃～+85℃, cycle time=2	1550, 1625	≤0.05
Soaking	Soak in 23℃±5℃ water for 30 days	1550, 1625	≤0.05

5.4.3 Mechanical properties after environmental test

The mechanical properties requirements after environmental tests shall conform to Table 11.

Table 11 - The mechanical properties requirements after environmental tests

Attribute	Mean peeling force N		Peak peeling force N		Tensile strength when Weibull distribution is 15%	Tensile strength when Weibull distribution is 50%	Dynamic fatigue parameter
	250μm	200μm	250μm	200μm			
Steady damp-heat	1.0～5.0	0.4～5.0	1.0～8.9	0.4～8.9	≥2.76 GPa a	≥3.03 GPa a	≥20 nd
Soaking	1.0～5.0	0.4～5.0	1.0～8.9	0.4～8.9	—	—	—
Gauge length 0.5m							

Appendix A (informative)

Application of CL fibre in WDM system

A.1 Overview

The traditional C-band 80-wave DWDM system and the extended C96 wave can no longer meet the demand of optical communication services for the continuous increase of network capacity. The capacity of WDM system can be increased by increasing the single channel rate and the number of system channels. Although the single-channel rate has reached 200 Gb/s and is developing to 400G, 800G or even 1T, restricted by Shannon–Hartley theorem, the transmission distance of signal decreases with the continuous improvement of spectral efficiency. Moreover, under the existing technical conditions, it is difficult to achieve continuous evolution by increasing spectral efficiency to improve single-fibre capacity. Therefore, it is necessary to further expand the band range and channel number of single fibre. There are currently two technology paths for extending the spectrum:

— Extended C band (extended C), can be extended from 80 waves to 96 waves

— C band +L band (C+L), can be extended from 80 waves to 192 waves

Typical optical spectrum expansion is shown in Fig. A.1

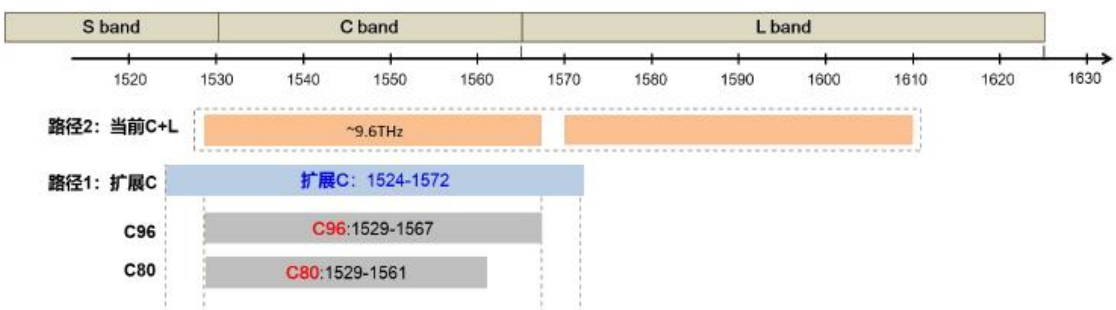

Fig.A.1 Schematic of optical spectrum expansion available for DWDM system

The technical scheme of extending C has been basically completed, and the C+L band technology needs to be further studied. C+L is to use the spectrum resources of C band and L band as the region of common spectrum transmission of the system, so as to realize the wavelength of 96 50GHz intervals in C band and L band respectively. Therefore, the total number of wavelengths of C+L can reach 192, and the spectral bandwidth can reach 9.6THz. Compared with extended C, C+L can effectively support 100% increase of system transmission capacity. Due to the constraints of physical characteristics and device functions, the performance of L band will deteriorate to some extent compared with that of C band, mainly due to the insertion loss of C/L combined split wave and stronger nonlinear effect. However, the performance degradation of the system in L band can be compensated by optimizing the attenuation characteristics of the fibre, which is CL fibre.

CL fibre is a new kind of fibre based on G.652D, which is formed by optimizing the attenuation performance of C+L band. According to ITU-T Recommendation G.652D, the attenuation coefficient of traditional G.652D at 1625nm is no more than 0.40dB/km, and the maximum attenuation coefficient is 0.30dB/km in the band 1530-1565.

Fibre	1260nm	1310nm	1383nm	1310~1625nm	1530~1565nm	1625nm
G.652D	Δ0.07	0.40	0.40	0.40	0.30	0.40
λcc Cut-off wavelength	≤1260					

Market research shows that the maximum attenuation coefficient of the domestically produced G.652D is no more than 0.30dB/km at 1625nm, and 0.20dB/km in the band 1530-1565. Typical C+L band attenuation curve in Fig.A.2

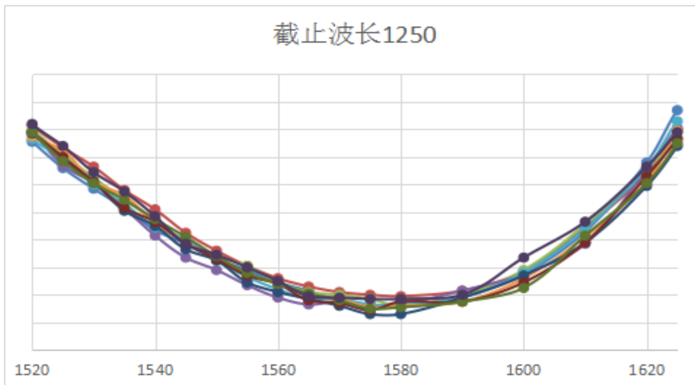

Fig.A.2 Typical attenuation curve of G.652D in C+L band

As can be seen from Fig.A.2, the attenuation curve of traditional G.652D in C+L band is not flat, especially at 1520nm and 1625nm, the attenuation coefficients are large, and FAWD appears. In order to better support the transmission of DWDM system in this band and offset the performance degradation of optical devices, some optimization can be made in attenuation flatness：Control the FAWD at 1520nm and 1625nm and limit FAWDD, thus ensuring the fibre's ability to support the system in the C+L band.

A.2 Method of selecting CL fibre

The data used in this method are from various actual products collected by APC from different manufacturers in China. In practice, CL fibres in compliance with this Recommendation can be quickly selected by classifying different cut-off wavelengths by sampling fibres of the same design according to the following steps.

A.2.1 Step 1: Test the optical fibre cut-off wavelength and attenuation spectrum

Optical fibres with different cut-off wavelengthsλc were selected and the attenuation spectra of all fibres were tested by PK2200. The cut-off wavelength section is divided into 5nm, and the attenuation spectrum test step is 5nm, ensuring that no less than 10 disks of attenuation spectrum data fall in each section.

A.2.2 Step 2: Analyse the attenuation spectrum distribution in different cut-off wavelengths

The attenuation data of the sections with cut-off wavelengthλc of 1230nm, 1235nm, 1240nm, 1245nm, 1250nm and 1255nm were selected respectively, and the attenuation spectrum of each disk was tested by PK2200, and the attenuation spectrum was obtained as shown in Fig.A.3 below:

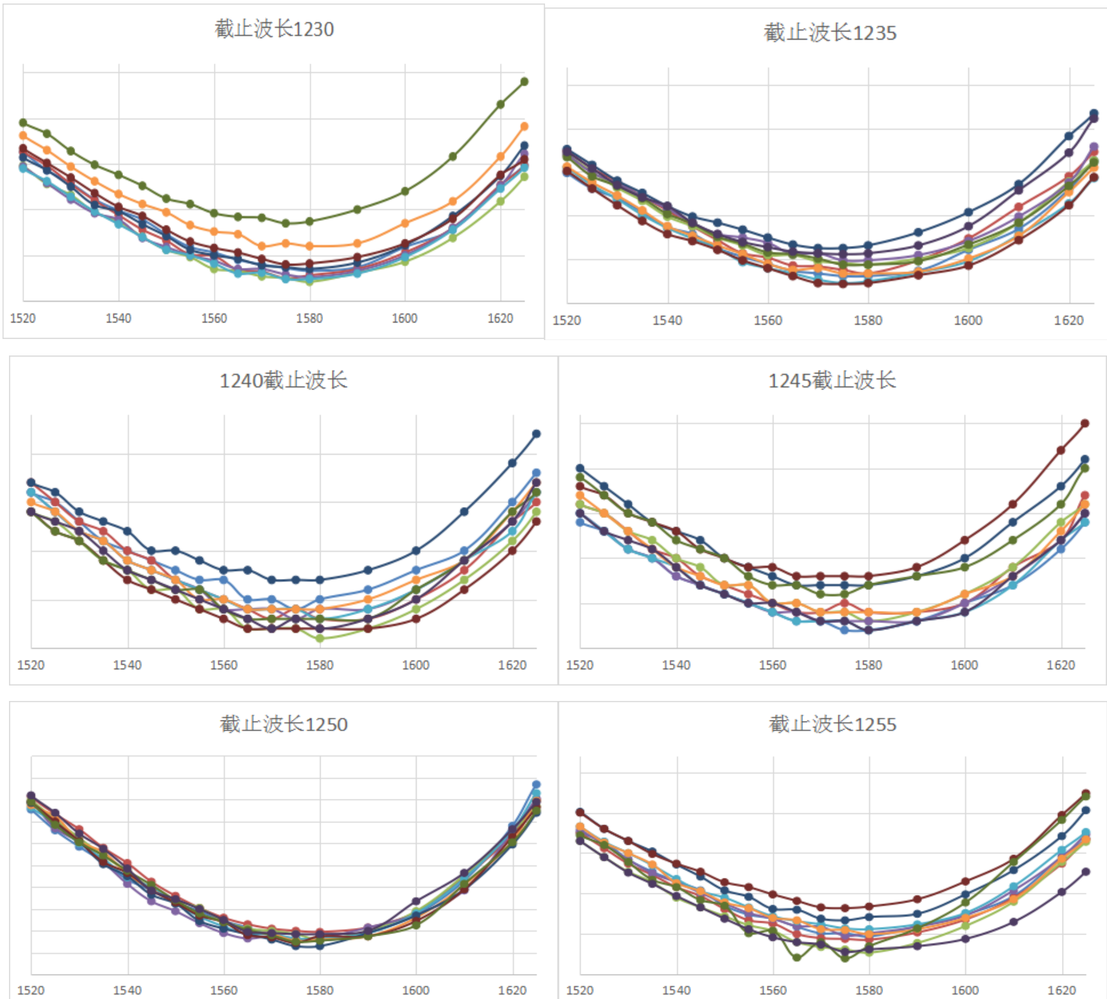

Fig.A.3 Attenuation spectra of 1520nm-1625nm at different cut-off wavelengths

A.2.3 Step 3: The optimal cut-off wavelength segment is obtained by analysis

Summarize the data and calculate the difference A between the minimum attenuation value of 1520nm~1625nm and 1520nm, B between the minimum attenuation value of 1520nm~1625nm and 1625nm, and the difference between A and B under different cut-off wavelengths. As shown in Table A.1, the comparison shows that when the cut-off wavelength is 1250nm, A and B are the smallest and the difference between A and B is the smallest.

Table A.1 Data analysis of difference A and B at different cut-off wavelengths

Cut-off wavelength	MaxA	MinA	Max B	MinB	MaxA-B	MinA-B
1230	0.0138	0.011	0.0155	0.0115	0.0015	-0.0045
1235	0.014	0.0113	0.0155	0.0117	0.0012	-0.0041
1240	0.014	0.01	0.015	0.011	0.002	-0.005
1245	0.013	0.01	0.017	0.012	0.001	-0.007
1250	0.0131	0.012	0.0143	0.012	0.0009	-0.0023
1255	0.0152	0.0118	0.02	0.0099	0.0038	-0.0048

Bibliography

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[3] GB/T 15972.40-2008 Specifications for optical fibre test methods—Part 40: Measurement methods and test procedures for transmission and optical characteristics—Attenuation.

[4] GB/T 15972.47-2021 Specifications for optical fibre test methods—Part 47: Measurement methods and test procedures for transmission and optical characteristics—Macrobending loss.

[5] C-Band extended Wavelength Division Multiplexing technical white paper.