Recent Standardization Activities in ITU-T on Single-mode Optical Fiber and Space Division Multiplexing Technologies

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Abstract

Optical fiber standards have been discussed in the International Telecommunication Union - Telecommunication Standardization Sector (ITU-T). Various standards (Recommendations) have been developed based on discussions at Study Group 15 and are revised according to the progress in the optical fiber telecommunication system. In this article, recent standardization activities in ITU-T on single-mode optical fiber (SMF) are described. Also, recent discussion toward standardizing space division multiplexing technologies, which are promising for overcoming the capacity limit of SMF, is introduced.

Keywords: single-mode optical fiber, space division multiplexing, ITU-T SG15

1. Introduction

The International Telecommunication Union - Telecommunication Standardization Sector (ITU-T) has developed many standards (Recommendations) to specify telecommunication system requirements, functions, and measurement methods to ensure the interoperability and quality of network services. Development of optical fiber standards is important, particularly for telecom operators, since transmission lines can consist of optical fibers provided from multiple vendors. Therefore, standardization on transmission and geometrical characteristics of optical fibers are mandatory to ensure the interoperability of the telecommunication system. **Table 1** shows the list of ITU-T Recommendations related to optical fibers. They are being developed under the responsibility of Study Group 15 (SG15) [1] Working Party 2 (WP2) Question 5. There are six types of Recommendations regarding single-mode optical fiber (SMF) (G.652–G.657). Question 5 has recently been discussing the revision of existing fiber Recommendations in accordance with the progress in optical fiber transmission technologies. Recommendations G.650.1–650.3, which are standard test methods for optical fibers, are revised in line with the revision of the fiber Recommendations. The G series Supplements are the supplemental documents that provide beneficial information for Recommendation users. The International Electrotechnical Commission (IEC) also has documents for optical fiber standards to describe fiber-product specifications and has developed them in conjunction with the revision of Recommendations in ITU-T.

2. Recent activities on SMF Recommendations

The Recommendations shown in red in Table 1 are those being actively discussed. The G.652 fiber is used worldwide and recognized as “standard SMF.” The G.657 fiber has optical characteristics compatible with those of G.652 fiber but has improved bending loss. These two fibers support transmission over the O–L band* (1260–1625 nm) and used for various applications such as access, metro, and core networks. Recommendation G.654 is for a fiber supporting

Table 1. List of optical fiber Recommendation series.

Category	Document No.	Title
Fiber	G.651.1	50/125 µm multimode graded index optical fibre cable
	G.652	Single-mode optical fibre and cable
	G.653	Dispersion-shifted single-mode optical fibre and cable
	G.654	Cut-off shifted single-mode optical fiber and cable
	G.655	Non-zero dispersion-shifted single-mode optical fiber and cable
	G.656	Fibre and cable with non-zero dispersion for wideband optical transport
	G.657	Bending-loss insensitive single-mode optical fibre and cable
Test method	G.650.1	Definitions and test methods for linear, deterministic attributes of single-mode fibre and cable
	G.650.2	Definitions and test methods for statistical and nonlinear related attributes of single-mode fibre and cable
	G.650.3	Test methods for installed single-mode optical fibre cable link
Supplement	G.Sup.40	Optical fibre and cable Recommendations and standards guideline
	G.Sup.47	General aspects of optical fibres and cables
	G.Sup.59	Guidance on optical fibre and cable reliability

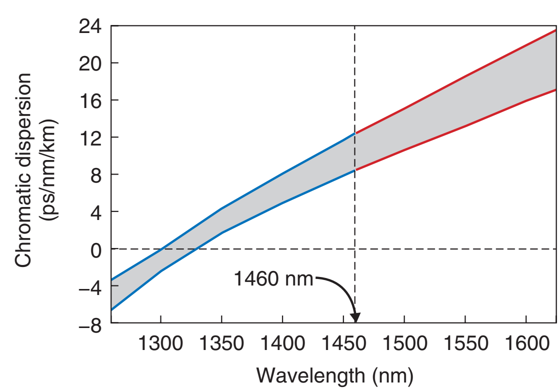
C–L-band* transmission and mainly used for submarine long-haul transmission systems. The revision of these Recommendations are active topics in ITU-T due to the capacity growth in terrestrial and submarine optical fiber networks. In the next section, recent activities for revising these SMF Recommendations are introduced.

2.1 Revision of Recommendations G.652/G.657

In this section, recent revisions to Recommendations G.652 and G.657 are introduced. ITU-T fiber Recommendation specifies, for example, fiber attenuation, mode field diameter (MFD), chromatic dispersion, or bending loss characteristics for satisfying the transmission-system requirements and for ensuring interoperability. The demand for specifying more detailed specifications has increased owing to the increase in the bitrate of transmission systems. Particularly, the wavelength properties of each parameter are becoming important because wavelength division multiplexing (WDM) transmission is an indispensable technology toward ultrahigh capacity transmission. From this background, ITU-T revised Recommendation G.652 in which the detailed wavelength property of chromatic dispersion for G.652.D fiber is specified. The revised specifications are shown in **Fig. 1**. Figure 1(a) shows the previous chromatic dispersion specifications in which the range of the zero dispersion wavelength λ_0 range and maximum dispersion slope at λ_0 are specified. The revised specifications for chromatic dispersion are now described in the latest Recommendation, i.e., G.652, which specifies the maximum and minimum dispersion values over the wavelength range of the O–L band, as illustrated in Fig. 1(b). The maximum or minimum dispersion boundary for 1260–1460 or 1460–1625 nm is

Parameter	Value
Zero dispersion wavelength λ_0	1300–1324 nm
Dispersion slope at λ_0 S_0	< 0.092 ps/nm^2 × km

(a) Previous specifications



(b) Revised specifications

Fig. 1. Chromatic dispersion specifications for G.652.D fiber.

* O-band (original band: 1260–1360 nm), C-band (conventional band: 1530–1565 nm), and L-band (long-wavelength band: 1565–1625 nm).

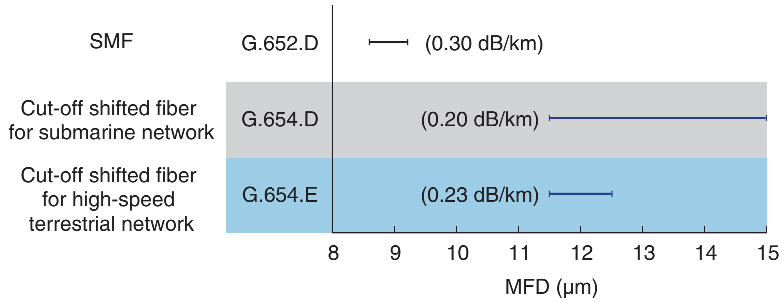


Fig. 2. Comparison of attenuation coefficient and MFD for G.652.D and G.654 fibers.

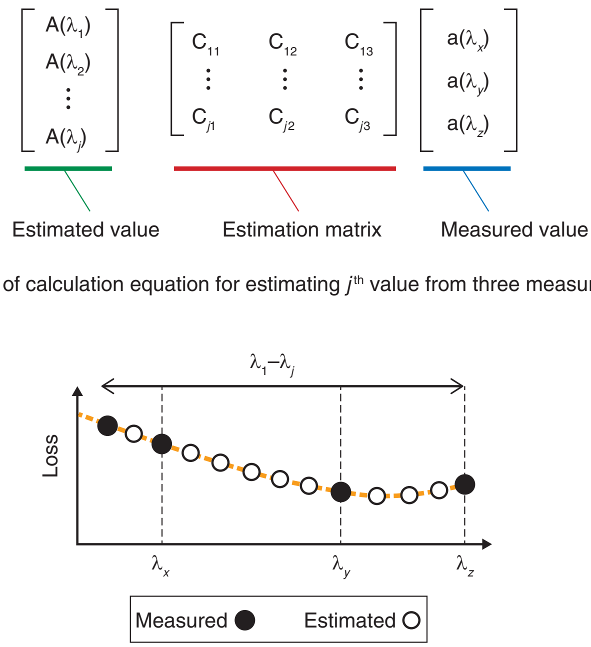
specified using an appropriate fitting function. This revision provides the full O–L-band chromatic dispersion characteristics of G.652.D fiber and helps system operators design the detail system configuration and requirements for future high-speed transmission systems. Since G.657.A fiber has compliant transmission, except for having low bending loss, the same chromatic dispersion specification was introduced in Recommendation G.657.

2.2 Revision of Recommendation G.654

Recommendation G.654 has been developed for use mainly in submarine networks. The features of G.654 fiber are low attenuation coefficient and large MFD compared with those of G.652 fiber, and transmission over low-loss transmission window, i.e., the C–L band, to support long-distance transmission systems. **Figure 2** summarizes the specified fiber attenuation coefficients and MFDs for G.654 subcategories. The loss attenuation and MFD for G.654 fiber are larger than those for G.652.D fiber. These characteristics are effective for improving signal quality (e.g. signal-to-noise ratio) by reducing the total span attenuation between repeaters or fiber nonlinearity-induced noise. The G.654.D fiber has the largest MFD and was developed for use in long-distance submarine networks. Although Recommendation G.654 was basically developed for submarine use, low loss and large MFD are also being required owing to the increase in the capacity and bitrate in terrestrial networks. The G.654E sub-category was established in 2016, which was for high-speed terrestrial core networks. The G.654.E fiber supports more than 100-Gbit/s-capacity transmission with a lower attenuation coefficient than that for G.652.D fiber and narrower MFD specification range than that for the other G.654 fibers by taking into account multi-vender fiber connections and compatible bending loss to ensure the applicability of the cable structure used in terrestrial networks.

2.3 Revision of Recommendation G.650.1

Recommendation G.650.1 specifies the test methods for optical fiber parameters such as attenuation coefficient and cut-off wavelength. In 2020, Recommendation G.650.1 was revised owing to the recent revisions of the fiber Recommendations in which the attenuation coefficient is specified by the maximum value at a specific wavelength or wavelength range. As fiber attenuation has wavelength dependency, it is important to know the loss spectrum to design a WDM transmission system. To support this requirement, Recommendation G.650.1 describes a method of estimating the attenuation spectrum from measured attenuation values at specific wavelengths. **Figure 3** shows a schematic diagram of this method, where a(λx) is the measured attenuation value at λx, and attenuation values A(λ1)–A(λj) can be estimated by multiplying the column vector [a(λx)–a(λz)] with the estimation matrix. The number of rows or columns of the estimation matrix corresponds to the number of estimated attenuation values or measured attenuation values, respectively. The figure also shows an example when *j* attenuation coefficients are estimated from the three measured attenuation values. It should be noted that the estimation matrix differs from the fiber product. Typically, 3–5 measured values are required to estimate the O–L-band attenuation spectrum. For recently established Recommendation G.654.E, it is beneficial to know the attenuation spectrum for this type of fiber to design high-capacity terrestrial networks. The applicability of the estimation method described in Recommendation G.650.1 for G.654.E fiber was recently investigated, and the validity of the attenuation-spectrum estimation over the C–L band from two measured attenuation



(a) Example of calculation equation for estimating j^{th} value from three measure values

(b) Schematic diagram for loss estimation

Fig. 3. Schematic image of attenuation-estimation method described in G.650.1.

values was confirmed, and Recommendation G.650.1 was revised accordingly.

In summary, the recent revisions of fiber Recommendations have focused on how optical characteristics can be specified for supporting terrestrial core or submarine long-haul networks with increased capacity or bitrate signals.

3. Recent activities on SDM standardization

Network capacity has been increasing at a rate of a few tens of percent, and the capacity crunch with SMF networks will become a serious issue in the 2020s. To overcome the capacity limit of SMF, fibers for space division multiplexing (SDM) transmission have been intensely investigated. **Figure 4(a)** shows the conceptual images of SDM fibers. SDM fibers can be basically categorized into two: multi-core fiber or multi-mode fiber. Multi-core fiber has multiple cores within a cladding, and multi-mode fiber has multiple propagation modes within a core. In SDM transmission, multiple signals can be simultaneously transmitted through multiple cores or modes, achieving much higher capacity compared with that in SMF. Before SDM fibers can be used in telecom networks worldwide, it is necessary to establish an SDM fiber Recommendation in the same manner as the SMF Recommendations. It was proposed and agreed at ITU-T 2020's January meeting to start discussion on a new technical report for SDM optical fiber and cable. Although the content of this technical report is under discussion, it was agreed to include the related topics on cable, splice/connectors, and installing technologies. The main discussion pointes are: target application and benefits of SDM technology and categorization of SDM fiber. Regarding the target application for SDM technologies, it is important to compare technologies that use SMF to improve spatial density, such as high-fiber-count cable or reduced coating-diameter fiber technologies, as shown in **Fig. 4(b)**. Although various SDM fibers have been proposed, current multi-core fiber- or few-mode fiber-based SDM fiber is being discussed as a potential candidate of SDM fiber. It is expected that the fiber parameters and test methods for such fibers will be discussed and incorporated into this technical report. The tentative publishing year for this technical report is 2022. The discussion on SDM fiber standardization has been initiated in advance in Japan, and the current technical level or challenges for SDM standardization has/have been summarized as technical report-1077 entitled "Technical Report on Space

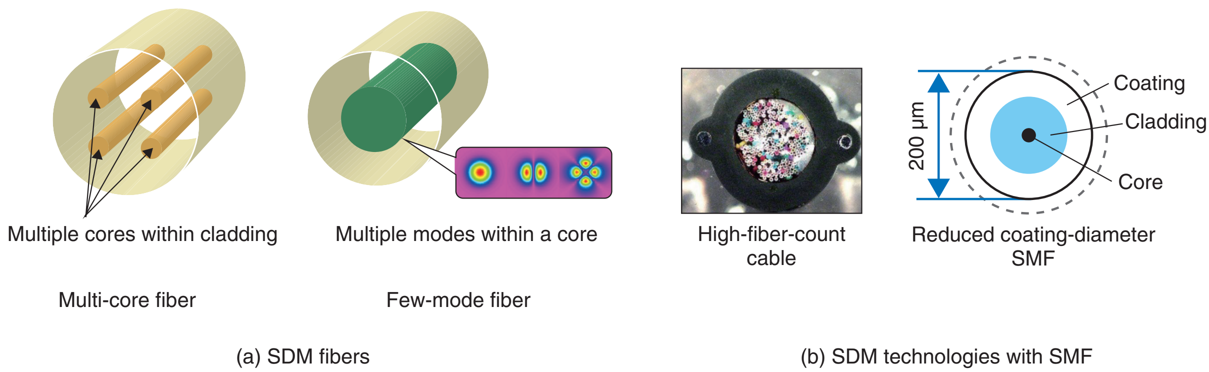


Fig. 4. SDM technologies discussed in ITU-T for developing new SDM technical report.

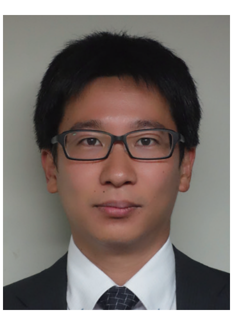
Division Multiplexing Technologies" (in Japanese) published by the Telecommunication Technology Committee (TTC) [2].

4. Summary

In ITU-T, the revision of SMF Recommendations has focused on how to support the increased capacity and bitrate transmission system over 100 Gbit/s, and each Recommendation has specified more detailed optical characteristics of the fiber. Regarding the SDM fiber standardization, the technical report on SDM fiber and cable, which will be published in 2022, is considered an important step in establishing an SDM fiber Recommendation. IEC has also decided to discuss the SDM fiber connector and amplifier standardization. We believe that SDM standardization, including fiber, cable or any other related component technologies, will be actively discussed and proceeded in cooperation with ITU-T and IEC.

References

[1] ITU-T SG15, https://www.itu.int/en/ITU-T/studygroups/2017-2020/15/Pages/default.aspx
[2] TTC TR-1077 (in Japanese), https://www.ttc.or.jp/document_db/information/view_express_entity/1238



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