SUMITOMO ELECTRIC TECHNICAL REVIEW

No. 96 · APRIL 2023

FEATURED TOPIC

Ultra-Low Loss ITU-T G.654.E Fiber "PureAdvance" for Terrestrial Optical Transmission Systems

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The PureAdvance series includes optical fibers with low attenuation of 0.17 dB/km or less and an enlarged effective core areas of 110 or 125 μm². These fibers are fully compliant with Recommendation ITU-T G.654.E, and suitable for terrestrial long-haul optical transmission systems. Sumitomo Electric Industries, Ltd. has improved the attenuation of PureAdvance to 0.16 dB/km or lower (typically 0.156 dB/km), and started the commercial supply. With the ultra-low attenuation, transmission performances of terrestrial long-haul optical links can be further improved, enabling high-speed optical transmission at 400 Gb/s and beyond. These fibers will contribute to the realization of high-capacity optical communication in terrestrial long-haul networks.

Keywords: optical fiber, G.654.E, low attenuation, pure-silica core optical fiber

1. Introduction

With the development of IoT/AI-based services and digital transformation (DX), data traffic continues to grow exponentially. As a digital infrastructure that underpins the growing data traffic, long-haul optical communication networks have become an indispensable lifeline of society, and there will be a continuous need for those with even higher capacity.

We have developed ultra-low loss ITU-T G.654.E[(1)]*1 fibers, PureAdvance series, for terrestrial optical transmission systems and started the commercial supply.[(2)] These fibers have been contributing to the economical realization of high-capacity optical transmission in terrestrial long-haul networks. This paper outlines the background of the increased attention to G.654.E fibers which feature low attenuation and large core areas as optical fibers for terrestrial long-haul applications. We then describe our latest development of the ultra-low loss G.654.E fibers PureAdvance, including a reduction in the attenuation to 0.16 dB/km or less. The benefits of PureAdvance for entire transmission systems will also be discussed.

2. G.654.E Fibers Suitable for Long-Haul High-Capacity Digital Coherent Transmission

First, we will describe the background of the increased attention to G.654.E fibers as optical fibers for terrestrial long-haul applications.

Figure 1 shows the evolution of the transmission capacity of commercialized long-haul optical transmission systems and the history of transmission technologies and optical fibers. Until the 2000s, intensity modulation/direct detection (IM-DD) had been mainly used in systems with a bit rate of 40 Gb/s or less. A major limiting factor of maximum transmission reach for the IM-DD systems was chromatic dispersion in optical fibers. Although IM-DD systems transmit digital information by switching optical pulses "on" or "off", the optical pulses broaden with transmission distance due to chromatic dispersion. As a consequence, it becomes difficult to distinguish the "on" or "off" of the broadened pulses after long-distance transmission. To suppress the pulse broadening, NZDSF having small chromatic dispersion, which complies with ITU-T G.655, was widely used in terrestrial backbone networks with a bit rate of 10 to 40 Gb/s. However, for a higher bit rate of 100 Gb/s or higher, even a small pulse broadening has a large adverse impact on the signal quality. Therefore, it would be technically and economically difficult to realize a long-haul transmission using the IM-DD method.

In contrast, digital coherent technologies, which transmit digital information using the intensity and phase of light, have been actively deployed since the 2010s. At the digital coherent receiver, optical signals are converted into electrical signals, and equalized by digital signal processing (DSP). Since the pulse broadening caused by

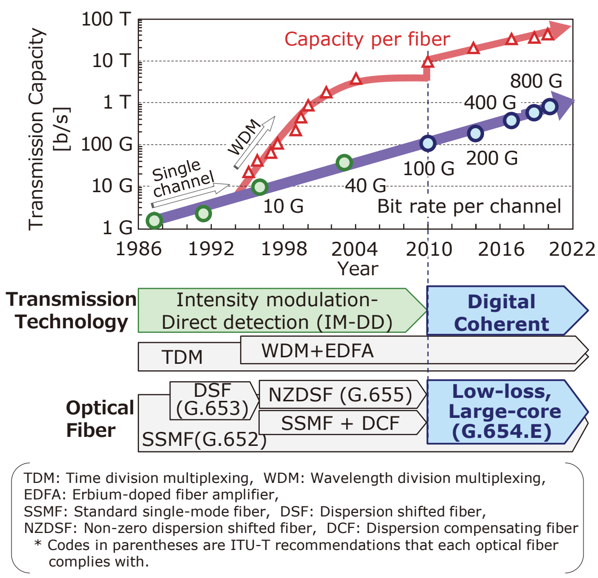

Fig. 1. Evolution of transmission capacity and history of transmission technologies and optical fibers

chromatic dispersion in optical fiber can be compensated by DSP, it became possible to achieve long-haul transmission even at a high bit rate of 100 Gb/s or higher.

The biggest challenge to further increase the transmission capacity for digital coherent systems is the improvement of the optical signal-to-noise ratio (OSNR).*2 For example, when doubling the bit rate from 100 Gb/s to 200 Gb/s, the transmission reach is theoretically reduced to about 1/5 with the same OSNR. To maintain the same transmission reach, the OSNR needs to be improved by about 7 dB (Fig. 2).

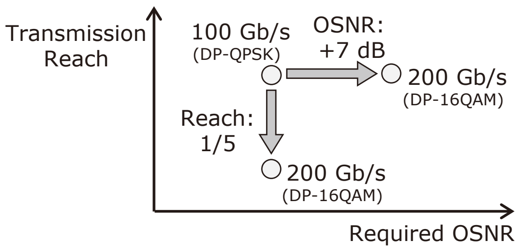

Fig. 2. Reduction in transmission reach and increase in required OSNR due to increase in bit rate

From this background, requirements for optical fibers have changed significantly. Although a key requirement for IM-DD systems was the suppression of chromatic dispersion, that for digital coherent systems is the improvement of OSNR. To improve the OSNR, the use of low attenuation and large core area fiber is one of the most effective means. Reducing the attenuation can increase the output optical power. Enlarging the core area can reduce the nonlinearity of optical fiber, and hence increase the maximum allowable input optical power. With these advantages, the OSNR can be effectively improved (Fig. 3). For this reason, ITU-T G.654.E fibers featuring low attenuation and large core areas have attracted much attention as the most suitable optical fibers for long-haul, high-capacity digital coherent transmission systems.

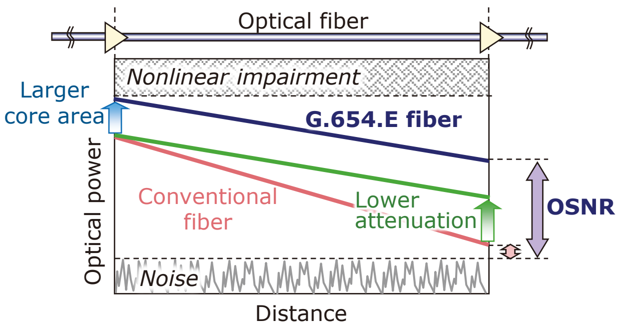

Fig. 3. OSNR improvement by low attenuation and large core area G.654.E fiber

3. G.654.E Fibers, PureAdvance

As a pioneer in the field of ultra-low loss optical fibers, Sumitomo Electric Industries, Ltd. has continuously developed pure-silica core optical fibers (PSCFs),*3 Z Fiber and Z-PLUS Fiber for more than 30 years,(3) and has been commercially supplying them mainly for submarine cable.(4) We have also achieved a world record for low attenuation of 0.1419 dB/km,(5) and succeeded in the world's first mass-production of PSCF having ultra-low attenuation of 0.144 dB/km, Z-PLUS Fiber 150 ULL.(6)

By applying the ultra-low loss PSCF technologies, we have developed terrestrial low loss optical fibers, PureAdvance series, and have been supplying them for terrestrial long-haul links with a bit rate of 100 Gb/s or higher.(2) Table 1 summarizes the fiber characteristics of PureAdvance-110 and PureAdvance-125, both of which are compliant with ITU-T G.654.E, and PureAdvance-80 having an MFD similar with that of SSMF, which is compliant with G.654.C or G.652.B.(7)

Through continuous development, we have improved the attenuation of PureAdvance-110 and -125 from 0.17 dB/km or less (typically 0.162 dB/km) to 0.16 dB/km or less (typically 0.156 dB/km) (Fig. 4), and started commercial supply of the improved ones in 2022. As far as we know, those are the world's lowest attenuation terrestrial optical fibers today. Figure 5 shows the attenuation distribution of conventional and improved fibers with a total length of over 100,000 km each. The average attenuation of the improved one is 0.156 dB/km. We have also confirmed that its standard deviation (σ) is as small as 0.001 dB/km.

In the meanwhile, since a cable length on a single spool is limited to several kilometers in actual terrestrial links, optical fibers would be spliced every several kilometers. In addition, optical fibers would be spliced with SSMF

Table 1. Fiber characteristics of PureAdvance

	PureBand (ref. SSMF)	**PureAdvance-80**	**PureAdvance-110**	**PureAdvance-125**	Rec. ITU-T G.654.E
ITU-T Rec.	G.652.D	G.654.C/G.652.B	G.654.E	G.654.E	G.654.E
Mode field diameter (MFD) @1550 nm	Typ. 10.3 µm	Typ. 10.1 µm	Typ. 11.7 µm	Typ. 12.5 µm	11.5-12.5 µm ±0.7 µm
Effective area (Aeff) @1550 nm	Typ. 80 µm²	Typ. 85 µm²	**Typ. 110 µm²**	**Typ. 125 µm²**	-
Attenuation @1550 nm	≤ 0.20 dB/km Typ. 0.19 dB/km	≤ 0.17 dB/km Typ. 0.165 dB/km	**≤ 0.16 dB/km Typ. 0.156 dB/km**	**≤ 0.16 dB/km Typ. 0.156 dB/km**	≤ 0.23 dB/km (Cabled)
Cable cut-off wavelength	≤ 1260 nm	≤ 1520 nm (G.654.C) ≤ 1260 nm (G.652.B)	≤ 1520 nm	≤ 1520 nm	≤ 1530 nm

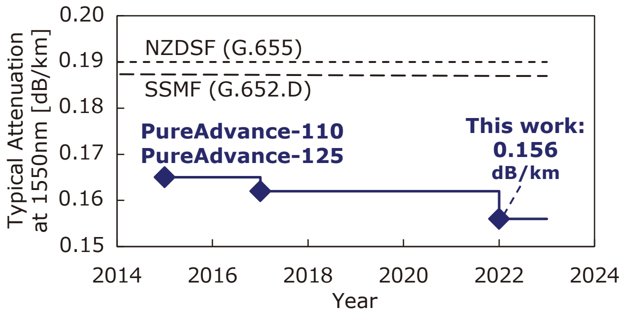

Fig. 4. Evolution of attenuation reduction of PureAdvance-110 and -125

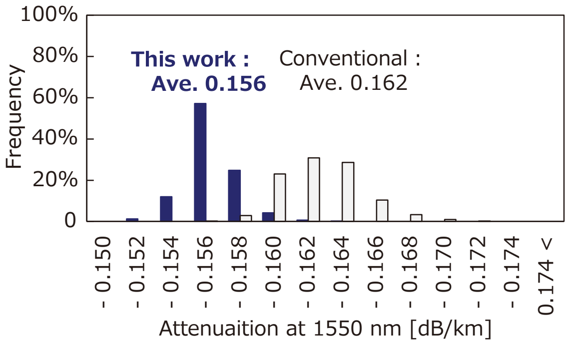

Fig. 5. Attenuation distribution of PureAdvance-110 and -125

pigtails of EDFAs or other equipment at repeater stations. Therefore, it should also be required to reduce the similar splice loss between the same type of fibers, and the dissimilar splice loss to SSMF. Table 2 shows typical splice losses of the PureAdvance series, which are calculated assuming the core misalignment between optical fibers of 0.3 µm.[8] From Table 2, the similar splice losses for PureAdvance-80, -110, and -125 are as low as that for an SSMF-SSMF splice. Although dissimilar splice losses between PureAdvance-110/-125 and SSMF are slightly higher than that for an SSMF-SSMF splice due to the MFD mismatching, PureAdvance-110 can be spliced with SSMF with a sufficiently low splice loss of less than 0.1 dB.

Next, to evaluate the transmission performance of PureAdvance, we calculated the transmission reach using a fiber figure-of-merit.[9],[10] The results are shown in Fig. 6. Here we assumed a bit rate of 200 Gb/s, and a repeater span length of 100 km. It is noted that the transmission reach depends on the performances of transceivers and EDFAs, the repeater span length, the number of splices, and cable

Table 2. Typical splice loss for PureAdvance series

	PureBand (Ref.)	PureAdvance -80	PureAdvance -110	PureAdvance -125
MFD (Typ.)	10.3 µm	10.1 µm	11.7 µm	12.5 µm
Similar splice loss	0.01 dB	0.01 dB	0.01 dB	0.01 dB
Dissimilar splice loss with SSMF (G.652.D)	0.01 dB	0.02 dB	0.08 dB	0.16 dB

installation conditions. In the case of Fig. 6, as an example, PureAdvance-110 featuring ultra-low attenuation and a large core area can improve the OSNR by +3.2 dB and +6.2 dB over SSMF and NZDSF, respectively, and thereby can significantly extend the transmission reach to 2.1 times that of SSMF and 4.2 times that of NZDSF. Furthermore, PureAdvance-125 can extend its reach to about 1.04 times that of PureAdvance-110.

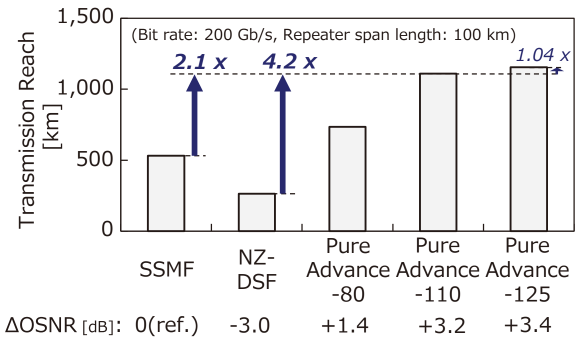

Fig. 6. Transmission reach of PureAdvance series at 200 Gb/s

4. Benefits of PureAdvance for Transmission Systems

By applying PureAdvance, the system can be constructed at a low cost, and is expected to have upgradability to a higher transmission capacity. In this chapter, we calculate the transmission reach of PureAdvance using the fiber figure-of-merit for two scenarios considering a 1,200 km terrestrial transmission link, and investigate the benefits of PureAdvance for the transmission system.

4-1 Scenario 1: Reduction in the number of repeaters in a 200 Gb/s transmission system

In long-haul optical transmission links, a repeater (EDFA) is required at every several tens of kilometers to amplify optical signals that are attenuated during propagation in optical fibers. Reducing the number of repeaters in the entire system is significantly beneficial for reducing the total system cost and the carbon footprint, because not only the equipment cost, but also the facility cost, electric power consumption, and the maintenance cost can be reduced.

In Fig. 7, we calculate the required repeater span length and the number of repeaters for 200 Gb/s transmission systems using (a) NZDSF, (b) SSMF, and (c) PureAdvance-110. First, a system using NZDSF cannot transmit 200 Gb/s signals over 760 km even if the repeater span length is reduced to 40 km or less. For this reason, it would be economically difficult to realize a 1,200 km transmission using NZDSF. In the case of SSMF, the repeater span length should be 55 km or less to achieve a 1,200 km transmission, that is, 21 repeaters will be required. On the other hand, for a system using PureAdvance-110 having ultra-low attenuation and a large core area, the repeater span length can be extended to 95 km, and the number of repeaters can be drastically reduced to 12.

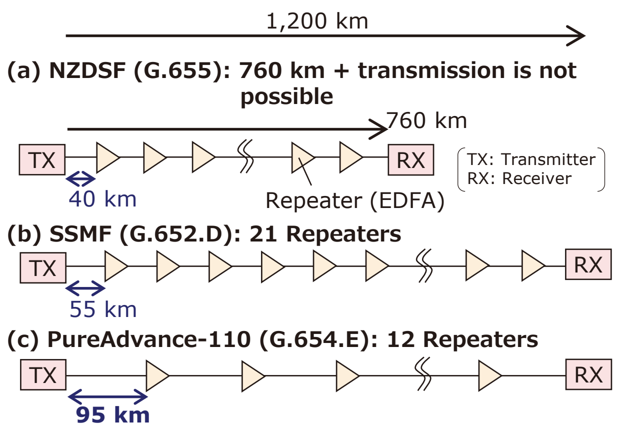

Fig. 7. Reduction in the number of repeaters in 200 Gb/s transmission

4-2 Scenario 2: Upgrade of the bit rate to 400 Gb/s

If the bit rate of optical signals is increased to 400 Gb/s, the transmission reach will decrease significantly, as in Fig. 2. Therefore, regenerator stations would be needed to regenerate the deteriorated optical signals. In a regenerator station, one regenerator*4 is installed for each signal channel. Therefore, a reduction of one regenerator station will lead to a significant reduction in the cost and power consumption of the entire system.

Figure 8 shows the calculated transmission reach and the number of regenerator stations for a bit rate of 400 Gb/s. Here, the repeater span length was assumed to be 80 km for systems with SSMF or PureAdvance-110, whereas that for the system with NZDSF was assumed to be 67 km because its transmission reach is significantly shorter than the other two types of fibers as in the previous section. As shown in Fig. 8, the transmission reach of NZDSF and SSMF is estimated to be 134 km and 240 km, respectively. Therefore, the number of regenerator stations required for a 1,200 km transmission link is 8 and 4, respectively. In contrast, a system using PureAdvance-110 can transmit over 400 km, and the number of regenerator stations can be reduced to 2. Therefore, PureAdvance-110 can contribute to realizing 1,200 km transmission at much lower system cost with much less power consumption than those for NZDSF or SSMF.

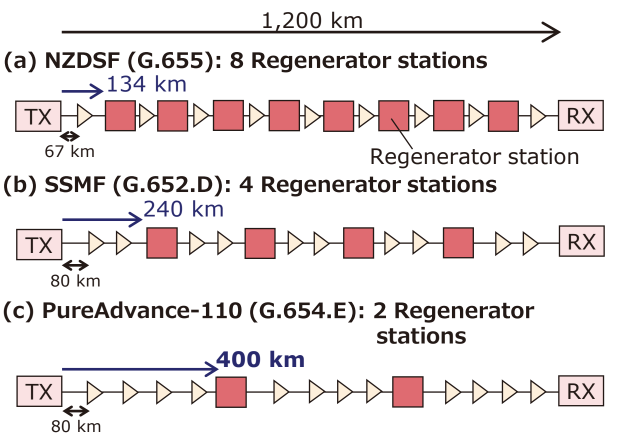

Fig. 8. Reduction in the number of regenerator stations in 400 Gb/s transmission

5. Conclusion

The PureAdvance series, compliant with Recommendation ITU-T G.654.E, is the most suitable optical fibers for long-haul digital coherent optical transmission systems with a bit rate of 400 Gb/s or higher due to their excellent features including ultra-low attenuation and large core areas. These fibers will contribute to the economical realization of high-capacity terrestrial long-haul optical transmission systems.

Sumitomo Electric will continue to develop and mass-produce ultra-low-loss optical fibers and provide products that meet the needs of society.

• PureAdvance, Z Fiber, Z-PLUS Fiber, and PureBand are trademarks or registered trademarks of Sumitomo Electric Industries, Ltd.

Technical Terms

*1 ITU-T G.654.E: ITU-T (International Telecommunication Union Telecommunication Standardization Sector) is a United Nations agency that develops international standards for ICT infrastructure, known as ITU-T Recommendations. G.654.E is a category of ITU-T recommendation that describes a cut-off shifted optical fiber and cable for terrestrial applications to support digital coherent transmission systems with a bit rate of 100 Gb/s or higher.

*2 Optical signal-to-noise ratio (OSNR): OSNR is the ratio of optical signal power to optical noise power. A higher OSNR is required to achieve higher signal quality because it is difficult to distinguish low OSNR signals from noise. In particular, high-capacity transmission systems require a higher OSNR.

*3 Pure-silica core fiber (PSCF): An optical fiber with a core made of pure silica (SiO_2). Since no dopant is contained in the core, in which most of the optical power of signals propagate, PSCF has inherently lower attenuation compared to SSMF and NZDSF, which have a GeO_2-doped core.

*4 Regenerator: An equipment to convert deteriorated optical signals into electrical signals, regenerate them by signal processing, and then convert the electric signals back into optical signals. The number of regenerators installed in a regenerator station is a multiplication of the number of WDM channels and the number of optical fibers in a cable.

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