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WHITE PAPER

Transition of Fiber Type for Terrestrial Long-Haul Networks, From G.655 to G.654.E

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1. Introduction

To keep up with the exponential growth of demand for global data traffic, fiber optic communication systems have continued to evolve to provide ever higher capacity transmitted over long distance. Figure 1 shows the evolution of transmission capacity of commercialized long-haul optical transmission systems, and the history of transmission technologies and optical fibers. The capacity has been increased by adoption of the latest transmission technology and optical fiber at each time. Especially, the substantial growth in the last decade has been enabled by digital coherent technologies with the bit rate of 100 – 800 Gb/s. To support such high-capacity transmission systems in terrestrial long-haul networks, low attenuation and large core area fibers compliant with Recommendation ITU-T G.654.E [1] have been introduced in the 2010s and actively deployed worldwide. Sumitomo Electric Industries, Ltd. developed and supplies PureAdvance-110 and PureAdvance-125 exhibiting ultra-low attenuation of 0.16 dB/km or less, which are fully compliant with ITU-T G.654.E.

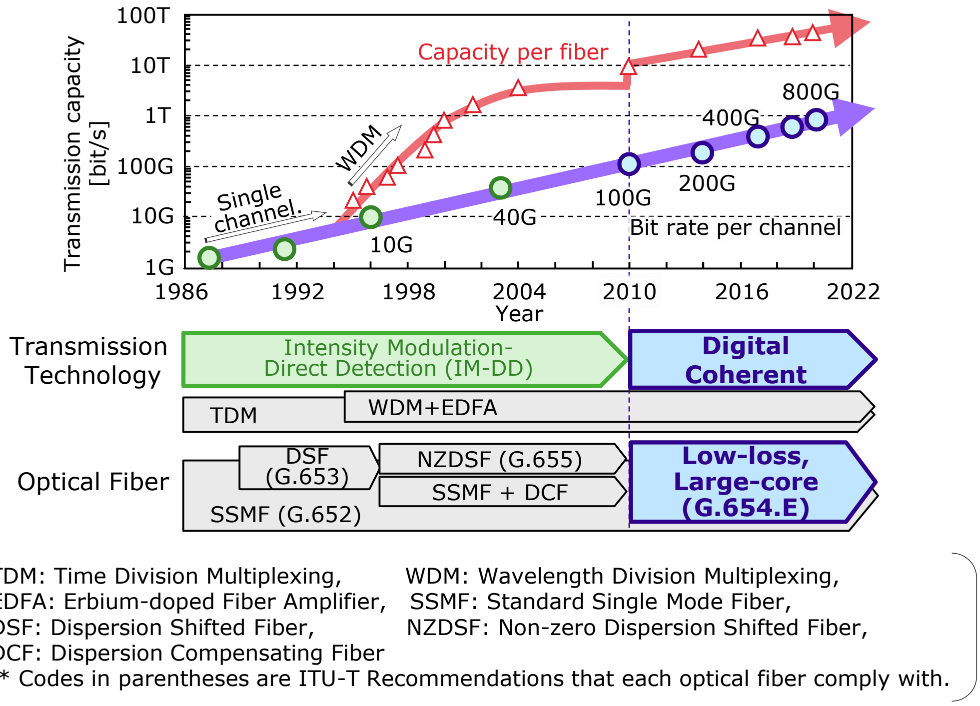

Fig. 1 Evolution of transmission capacity, and history of transmission technologies and Fibers.

This whitepaper reviews the transition of fiber type suitable for terrestrial long-haul networks along with the evolution of transmission technologies, in which the fiber type has been drastically changed from ITU-T G.655 (2) to G.654.E in the 2010s.

2. G.655 fibers for IM-DD systems

Until the 2000s, intensity modulation-direct detection (IM-DD) had been mainly utilized for systems with the bit rate of up to 40 Gb/s. IM-DD systems carry digital information "1" or "0" by switching optical pulses "on" or "off" and transmit the pulses through an optical fiber. However, the optical pulses are broadened with the transmission distance due to chromatic dispersion (CD) and polarization mode dispersion (PMD) in the optical fiber. The broaden pulses would be overlapped with sequential pulses after propagating through an optical fiber, and thereby, it becomes difficult to distinguish "on" or "off" of the pulses at the receiver side. Although optical signals at around the 1550 nm wavelength region, at which attenuation is minimized, are generally used for long-haul transmission, the CD of SSMF at 1550 nm is relatively high, typically around 17 ps/nm/km. Therefore, the CD was a major limiting factor of the maximum transmission reach for IM-DD systems. One method to suppress the pulse broadening due to CD was to insert a dispersion compensating fiber (DCF) module in front of the receiver. DCF has a large negative CD, and it can compensate the pulse broadening due to CD (Fig.2 (a-1)). However, a DCF module would be bulky and lossy.

Alternative approach to suppress the pulse broadening due to CD was adoption of NZDSF instead of SSMF. NZDSF complying with Recommendation ITU-T G.655 has a small CD at the 1550 nm wavelength region, and thereby, the pulse broadening can be suppressed (Fig.2 (a-2)). Hence NZDSFs had been used for 10 – 40 Gb/s terrestrial transmission systems in the 1990s and 2000s. However, for a higher bit rate of 100 Gb/s or higher, long-haul transmission would not be technically and economically feasible even with NZDSF, because very small broadening of optical pulses can bring a significant adverse impact on the signal quality.

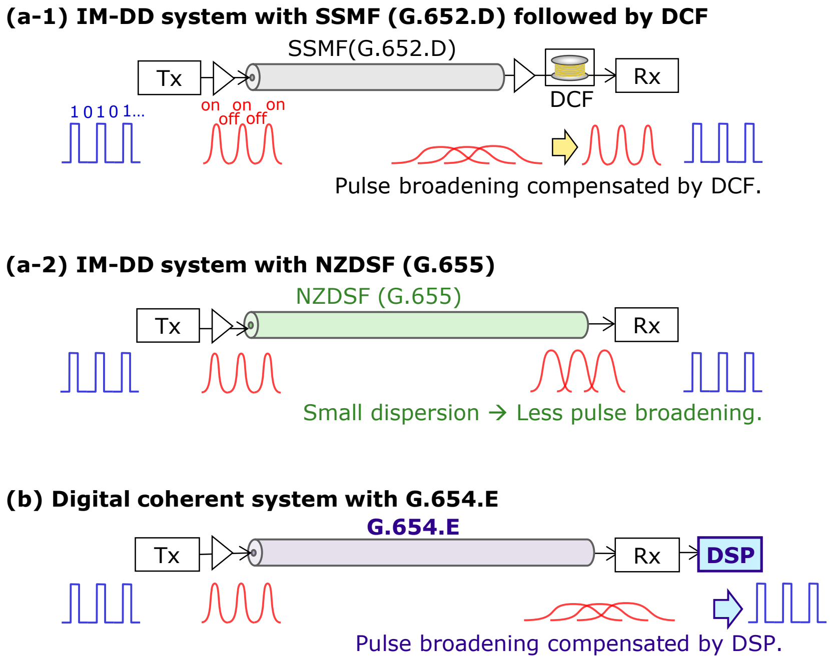

Fig. 2 Compensation of CD-induced pulse broadening in (a) IM-DD systems with SSMF or NZDSF, and (b) digital coherent system with G.654.E fiber.

3. G.654.E fibers for digital coherent systems

In the 2010s, transmission systems based on digital coherent technologies which carry digital information by intensity and phase of light have been introduced and actively installed. At the digital coherent receiver, received optical signals are converted into electrical signals, and the signal distortions can be equalized by digital signal processor (DSP). Since the pulse broadenings due to CD and PMD can also be compensated by DSP (Fig.2 (b)), it became possible to achieve long-distance transmission even at a high bit rate of 100 Gb/s and higher.

To further increase the transmission capacity of digital coherent systems, it is necessary to improve the optical signal-to-noise ratio (OSNR). OSNR is a power ratio of the optical signal to the noise after transmitting through an optical link, and it is generally dominated by two types of noises; amplified spontaneous emission (ASE) noise generated by optical amplifiers that compensate an attenuation, and nonlinear noise generated by nonlinear phenomena in optical fibers. Therefore, reduction of the attenuation and suppression of the nonlinearity by enlarging core area are ones of the most effective means to increase the OSNR.

From this background, requirement on optical fiber for long-haul transmission has been drastically changed – Although a key requirement for IM-DD systems was "smaller CD", that for digital coherent system is "lower attenuation and larger core area". Therefore, low attenuation and large core area fiber compliant with Recommendation ITU-T G.654.E has been introduced and actively deployed to enable high-capacity digital coherent transmissions in long-haul terrestrial networks.

The comparison of attributes of Recommendations ITU-T G.652.D(3), G.655.D and G.654.E is summarized in Table 1.

Table 1 Attribute comparison among ITU-T G.652.D, G.655.D, and G.654.E (Excerpt).

	ITU-T G.652.D	ITU-T G.655.D	ITU-T G.654.E
Mode field diameter (MFD) @1310nm [μm]	8.6-9.2 (±0.4)	-	-
Mode field diameter (MFD) @1550nm [μm]	-	8-11 (±0.7)	11.5-12.5 (±0.7)
Effective area (A_{ef}f) @1550nm [μm^2]	Typ. 80*1	Typ. 50-72*1	Typ. 110-125*1
Attenuation @1550nm [dB/km]	≤ 0.3 (Cabled)	≤ 0.35 (Cabled)	≤ 0.23 (Cabled)
Chromatic Dispersion @1550nm [ps/nm/km]	13.3-18.6*2	2.80–6.20*3	17-23
Macrobending loss (r=30mm) @1625nm [dB/100turns]	≤ 0.1	≤ 0.1	≤ 0.1
Cable cut-off wavelength [nm]	≤ 1260	≤ 1450	≤ 1530
Features	Standard SMF	Small dispersion	Low attenuation & large core, for high bit-rate digital coherent transmission

*1: Typical value. A_{eff} is not specified in ITU-T Recommendations.
*2: Zero dispersion wavelength and chromatic dispersion at 1625nm are also specified.
*3: Chromatic dispersion is specified with a wavelength range of 1460-1625nm.

Sumitomo Electric developed and supplies terrestrial long-haul fibers, PureAdvance-110 and PureAdvance-125 fully complying with ITU-T G.654.E. By applying Sumitomo Electric's matured pure-silica core fiber technologies that have been cultivated since the first launch of submarine fibers in 1989 to the manufacturing, PureAdvance-110 and PureAdvance-125 realize ultra-low attenuation of 0.16 dB/km or less (typically 0.156 dB/km) at 1550 nm (2), which exhibits the world's lowest attenuation among commercial terrestrial fibers today, to the best of our knowledge. PureAdavance-110 and PureAdvance-125 also have large effective areas of 110 and 125 μm^2 typically at 1550 nm, respectively, whereas that of G.652.D SSMF is typically 80 μm^2. With the features including ultra-low attenuation and large core area, PureAdvance-110 and PureAdvance-125 can significantly extend the transmission reach compared to SSMF and NZDSF (5). By applying PureAdvance-110 or PureAdvance-125, the transmission systems can be constructed with a low cost, and is expected to have an upgradability to higher capacity with the bit rate of 400 Gb/s, 800 Gb/s and beyond.

4. Conclusion

With the advent of digital coherent technologies at a bit rate of 100 Gb/s and higher in the 2010s, the fiber type for terrestrial long-haul networks had been significantly changed – from G.655 to G.654.E. Sumitomo Electric's ultra-low attenuation ITU-T G.654.E fibers, PureAdvance-110 and PureAdvance-125 are the most suitable fibers for terrestrial long-haul optical links today and in the future, enabling high-capacity digital coherent transmissions at 400 Gb/s and beyond. The fibers will contribute to the realization of high-capacity optical communication at a low overall cost in terrestrial long-haul networks.

References

1. Recommendation ITU-T G.654 (2020)
2. Recommendation ITU-T G.655 (2009)
3. Recommendation ITU-T G.652 (2016)
4. Sumitomo Electric Fiber Optic Products Website, Ultra-low loss terrestrial long-haul fibers PureAdvance series; https://global-sei.com/fttx/optical-fibers/pureadvance/
5. Sumitomo Electric WHITE PAPER, TR-23xxxA, "ITU-T G.654.E Fiber for Terrestrial Long-Haul Networks" (2023)