Optical Link Characteristics and Long-Term Stability of High-density Multi-Core Fiber Cables Deployed in the Terrestrial Field

Yusuke Yamada, Takayoshi MORI, Takashi Matsui, Masashi Kikuchi, and Kazuhide Nakajima
Access Network Service Systems Labs., NTT Corporation, 1-7-1, Hanabatake, Tsukuba, Ibaraki, 305-0805, Japan
yuusuke.yamada.ze@hco.ntt.co.jp

Abstract: The feasibility of a standard 125-μm-cladding multi-core-fiber-based high-density terrestrial cable is described including long-term stability in an underground facility. The impact of a core-rotating splice on the link loss is also investigated.

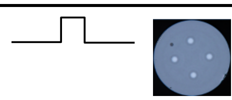
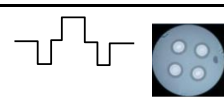
1. Introduction

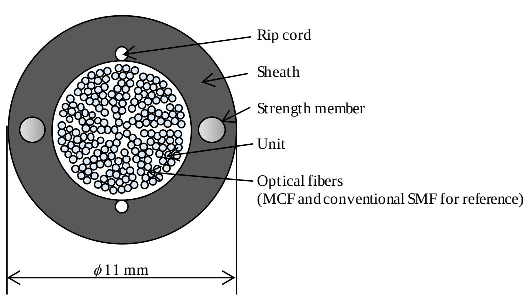
The standard cladding diameter multi-core fiber (MCF) minimizes the effect on the manufacturability and enables the use of standard technologies and know-how such as existing optical cables and connection technology [1]. Furthermore, optical characteristics compatible with a conventional single-mode optical fiber (SMF) makes it possible to use with existing transmission systems, so early implementation is expected. It is also important to consider the limitation of existing infrastructures in metro/core networks. Using the existing space of an underground duct is an effective way to economically and sustainably expand the terrestrial network. In particular, multiple cable installation technology for underground ducts has been developed and widely used in the terrestrial network [2]. In construction using this method in the terrestrial network, the cable outer diameter is limited to be about 20 mm. Therefore, it is desirable to apply MCFs because simply increasing the number of optical fibers will reach its limit in the future. In this paper, we describe the design and characteristics of the standard cladding diameter MCF cable and investigate the characteristics of the cable deployed in the terrestrial field.

2. Design of multi-core fiber cable

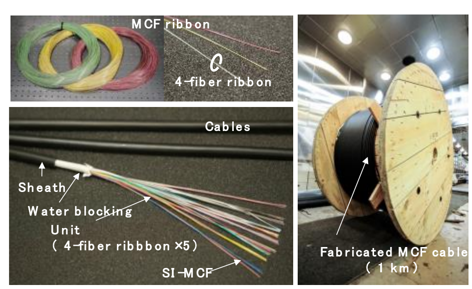
Table 1 shows the designs of standard cladding 4-core fibers that have been proposed [1]. These fibers have been developed using the conventional step index (SI), trench assisted (TA), and W-shaped (depressed) profiles, and they ensure optical compatibility to existing SMF standards. Thus, these MCFs can be potentially applied to high-density cables.

Table 1 Examples of standard cladding diameter MCFs compatible with conventional SMFs

Single-mode band	Full-band (O to L)		Low-loss band (C, L)
Optical compatibility	G.652/G.657		G.654
Index profile and fabricated example	 SI-MCF	 TA-MCF	 W-MCF
XT at 1550 nm(km^{-1})	$<10^{-1}$	$<10^{-5}$	$<10^{-7}$
Application	Access NW/DCI	Core/Metro	Submarine



(a) Cross-sectional structure of high-density MCF cable



(b) Fabricated fiber ribbon and cable

Fig. 1. Configuration of high-density MCF cable

To maximize the spatial density of the cable, a tightly accommodated high-density cable structure is desirable. Figure 1 (a) shows the configuration of a high-density MCF cable using a partially-bonded optical fiber ribbon. This cable is composed of fifty 4-fiber ribbons, strength members, rip cords, and a sheath. The cable has ten fiber-units containing five fiber ribbons, and each unit is stranded. The outer diameter is 11 mm. Figure 1 (b) shows the appearance of the fabricated optical fiber ribbon and cable. Fifty MCFs and conventional SMFs were included in the cable.

2. Cable characteristics

Figure 2 shows the optical loss characteristics of the fabricated MCF cables. Here, cabling loss is the difference in attenuation coefficient between the fiber spooled on the bobbin and cable spooled on the reel. The blue and red filled circles are the cabling loss of SI-MCF and TA-MCF cables, respectively. The blue and red open squares indicate the conventional SMF for reference. Figure 2 confirms that the difference in the average cabling losses is less than 0.05 dB/km at each wavelength and stable characteristics are achieved. Here, the maximum cabling loss value indicated by the error bar in the SI-MCF cable is slightly increased. The conventional SMF also has increased optical loss, which increases with longer wavelengths, and is considered to be micro-bend loss caused by cable structural conditions. The variation in the loss of the conventional SMF is because it includes the variation in commercial products that were mass-produced. Assuming that the attenuation in a typical fiber is 0.2 dB/km at a wavelength of 1550 nm, the attenuation after cabling is less than 0.3 dB/km, which meets ITU-T G.652 or G.657 and is acceptable. Moreover, it is known that such cabling losses can be suppressed, for example, by controlling the inner diameter of the cable [5]. In addition, because the average cabling loss is sufficiently low, this cabling loss could be improved. The cabling losses of the SI-MCF were more varied than those of the TA-MCF. We consider that the TA profile is used in bend-insensitive fibers and that the cabling loss is suppressed.

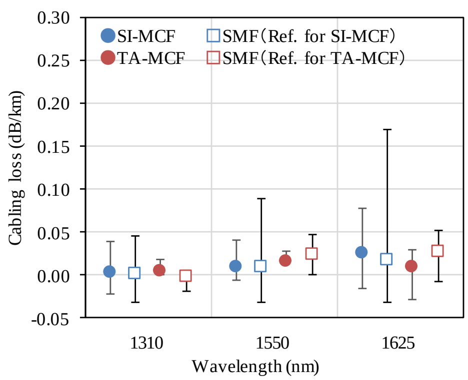


Fig. 2. Cabling loss characteristics of MCFs and conventional SMF

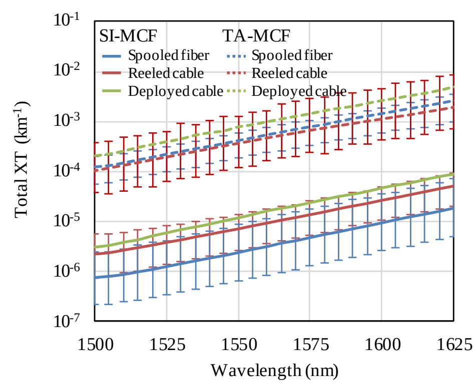


Fig. 3. XT change during cabling process

Figure 3 shows the crosstalk (XT) characteristics of the fabricated MCF cable. The dashed and solid lines indicate the XT of SI-MCF and TA-MCF, respectively. The blue, red, and green lines indicate the spooled fiber, reeled cable, and deployed cable, respectively. The XT of SI-MCF and TA-MCF were $10^{-3.45\pm0.25}$ km^{-1} and $10^{-3.38\pm0.50}$ km^{-1}, and $10^{-5.60\pm0.55}$ km^{-1} and $10^{5.15\pm0.40}$ km^{-1} at a wavelength of 1550 nm, respectively. The average XT change was about $10^{0.05}$ km^{-1} for each MCF. It is known that XT varies depending on the bending radius [6]. Therefore, we consider that the XT changes correspond to the effective bending radius difference among the spooled, reeled, and installed conditions [7].

When a cable is deployed in the field, mechanical external forces such as bending and tension are applied, and then it is used over a long term under environmental changes. Therefore, it is important to understand the aging characteristics of the laid cables. Figure 4 shows a schematic of underground facilities for a field deployment test. The fabricated SI-MCF cable was installed on a 500 m long underground tunnel. The cable was supplied from the cable reel on the ground and bending under tension was induced on the puller for curve guide equipment.

Figure 5 shows the long-term characteristics of the optical loss and XT in the deployed SI-MCF cable. The horizontal axis is the elapsed time, and the cables were measured over a period of about 1 year after deploying. The temperature of the underground field ranged from 0 to 30° C and the relative humidity was 20 to 100% with condensation. The optical loss without the splice point was measured by an optical time-domain reflectometer (OTDR) at 1550 and 1625 nm. The optical loss change was less than ±0.03 dB/km at a wavelength of 1550 nm, which confirms that stable characteristics are comparable to the conventional SMF. The XT was measured in an optical cable 15 km long with fifteen spliced SI-MCFs. The XT of the deployed cable was $10^{-3.18}$ km^{-1} at a wavelength of 1550 nm, an increase of

$10^{0.2}$ km^{-1} compared with the average value before being deployed. The cause of the XT change is considered to be a change in the bending radius of the fiber. The maximum change in XT during the test period was $10^{\pm 0.02}$ km^{-1} at a wavelength of 1550 nm, and sufficiently stable characteristics were confirmed.

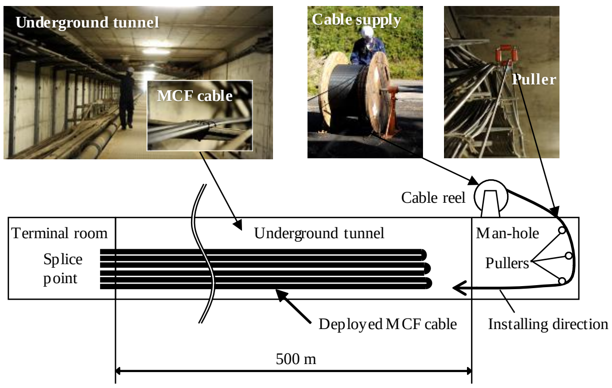


Fig. 4. Schematic of field deployment test

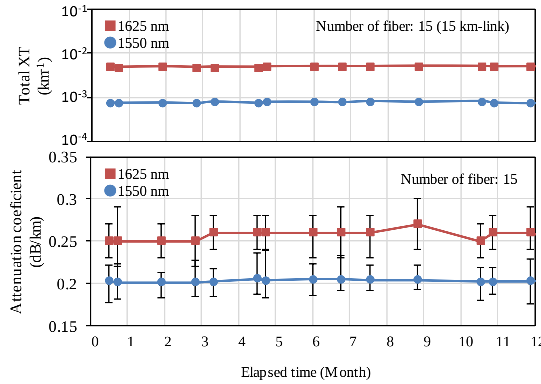


Fig. 5. Long-term characteristics of deployed MCF cables

It is important to investigate the effect of the splicing point management on the splice loss in an MCF link. A 30-km-long MCF link was composed by splicing three cables provided by different manufacturers, and the link characteristics were measured. Figure 6 is a histogram of splice losses in a link that interconnects the MCFs. Figure 6(a) and (b) are the splice loss of the link with the same core alignment and the link with the core-rotating alignment, respectively. The loss was measured by a bi-directional OTDR at a wavelength of 1550 nm. The average splice loss and standard deviation σ of the same core alignment and core-rotating alignment were 0.53 dB, σ=0.34 dB and 0.29 dB, σ=0.19 dB, respectively. We found that the core-rotating connection statistically averages the connection loss and also suppresses the standard deviation. Therefore, the core-rotating splice is effective for reducing the core-to-core deviation of the transmission link.

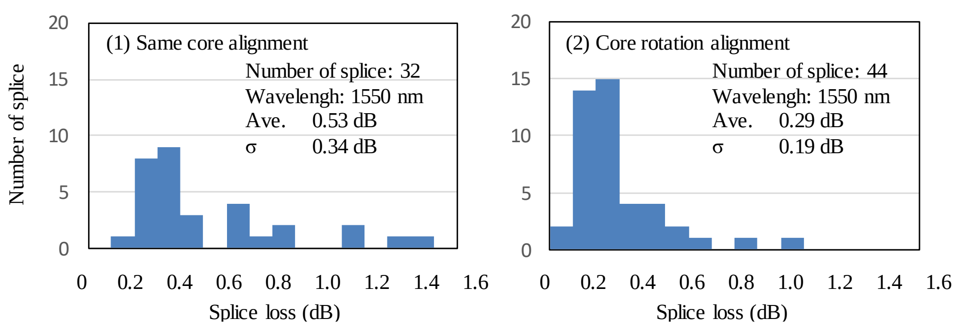


Fig. 6. Core alignment dependence of TA-MCF splice loss variation

3. Conclusion

We described the feasibility of high-density cables with the standard cladding diameter multi-core fiber. The applicability of the SI-MCF and TA-MCF to high-density cables was experimentally revealed. In the terrestrial field, long-term stability of optical loss and crosstalk has been confirmed. We found that the core-rotating connection statistically averages the splice loss and also suppresses the standard deviation. Further discussion on the relationship between installation conditions and optical link properties will support the deployment of the MCF terrestrial link.

4. Acknowledgement

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5. References

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