W1F.6.pdf
Optical Fiber Communication Conference (OFC) © 2026 Optica Publishing Group

Mass Production of Two-core Fiber and Applicability for Pb/s Submarine Cable

Yuki Kawaguchi, Hirotaka Sakuma, Tetsuya Haruna, Tetsuya Hayashi, Hideki Yamaguchi, Masaaki Hirano, and Takemi Hasegawa
Sumitomo Electric Industries, Ltd., 1, Taya-cho, Sakae-ku 244-8588 Yokohama, Japan.
kawaguchi-yuuki1@sei.co.jp

Abstract: We report mass production of 2-core-fiber(2CF) with Aeff of 112μm² and demonstrate ultra-low-loss of 0.155dB/km, negligibly low XT, and low PMD. Using mass production results, we clarify feasibility of 2CF to construct 1Pb/s transoceanic system. © 2025 The Author(s)

1. Introduction

Spatial division multiplexing (SDM) is now the most promising way to increase the capacity and to improve the power efficiency of submarine cables. Currently, 0.5 Pb/s transoceanic system is realized with a 24 fiber pair (FP) cable, and to increase a cable capacity further toward 1 Pb/s, multi-core fiber (MCF) cable is one of promising solutions [1-6]. Actually, uncoupled two-core fiber (2CF) is going to be introduced to the next generation of SDM in submarine cables [7]. In order to apply MCF to practical optical transmission system, not only MCF but also eco-system should be realized. For smooth transition to MCF eco-system, optical equipment and devices compatible with existing single-core fiber (SCF) system should be adopted as much as possible. With utilizing Fan-in/Fan-out (FIFO) devices [4], existing transmitter, receiver and Erbium-doped fiber amplifier (EDFA) can be applied [6].

In this paper, we report manufacturing statistics of 2CF indicating excellent optical performance including ultra-low loss, negligibly low inter-core crosstalk (XT), low polarization mode dispersion (PMD), low splice loss. In addition, we also show its feasibility to 1 Pb/s transoceanic system.

2. Design and manufacturing of 2CF

We applied a shifted-core configuration where two cores are arranged so that the distance to the cladding center is different as shown in Fig.1. This asymmetric configuration has the mirror-symmetric end face. Therefore, the 2CF has no polarity. The polarity free can be spliced to both end faces of another 2CF, which has various advantages including no-need to manage 2CF direction at cable manufacture, deployment and repair work, detection of identification failure at splicing (high splicing loss), no-need of marker in 2CF.

A heterogeneous-core configuration was applied for the 2CF. A heterogeneous core MCF having a slightly different refractive indexes between cores is known as an effective design for preventing XT degradation in the actual submarine cable production because it causes the XT to decrease as the bending radius increases [8,9]. Actually, we showed that the XT of heterogeneous 2CF would be suppressed after a submarine cabling [10]. With the configuration, we manufactured 2CF designed to have Aeff of 112 μm^2, chromatic dispersion of 21 ps/nm/km, cladding diameter of 125 μm, and outer diameter of 250 μm, with cumulative lengths of approximately 10,000 km.

Figure 2 shows attenuation distribution of manufactured 2CF. An average attenuation was equivalent to a single-core fiber for submarine applications, 0.155 dB/km at 1550 nm. The distribution appears to be Gaussian in shape, exhibiting a small standard deviation of 0.003 dB/km.

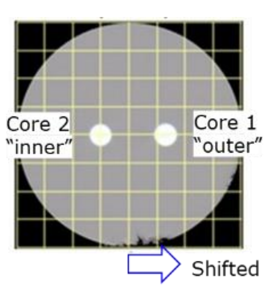

Fig. 1. End view of manufactured 2CF.

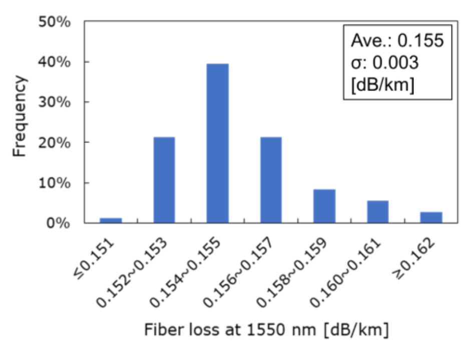

Fig. 2. Loss distribution of 2CF.

XT is one of the most important optical characteristics of uncoupled MCFs because high XT causes additional noise and consequently degrades the system SNR. It was reported that XT of -45 dB or less at a span length would have a negligibly small deterioration of OSNR penalty, and above -40 dB, OSNR will rapidly increase at higher XT [11]. Accordingly, mitigating XT is one of major challenges to realize submarine ultra-long haul MCF system, and an effective way is to adopt counter-propagation scheme in which signals propagate in neighboring cores in the counter direction. We theoretically clarified that a counter-propagation scheme can suppress a XT by around 20 dB compared to a XT with a co-propagation scheme in which signals in cores propagate in the same direction [12]. Figure 3 shows distribution of counter-propagation XT at a fiber length of 100 km of mass-produced 2CF. The XT was measured for 2CF wound on a shipping bobbin with an inner diameter of 168 mm. The average and the maximum values were 1.1 x 10^{-5} (-50 dB) and 4.0 x 10^{-5} (-44 dB), respectively. We would be able to safely state that a submarine cable with the manufactured 2CF would have negligibly small OSNR penalty induced by XT with counter-propagation scheme because the heterogeneous core configuration was applied to the 2CF [10].

Figure 4 shows a distribution of PMD under a loosely coiled condition simulating submarine cabling. We successfully realized excellent PMD as low as 0.03 ps/km$^{1/2}$ in average, although circumferential non-uniform residual stress around each off-centred core in MCF may induce a high birefringence. Figure 5 shows a distribution of splice loss between 2CFs. We demonstrated low splice loss, which is the result of our capability to manufacture a configuration of MCF with high precision.

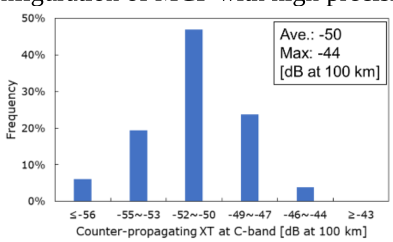

Fig.3. Counter-propagating XT of 2CF

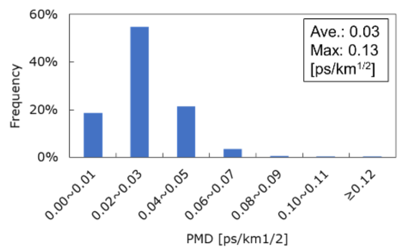

Fig.4. PMD of 2CF

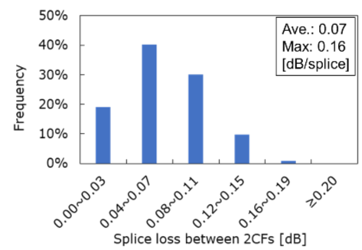

Fig.5. Splice loss between 2CFs

3. Viability to transoceanic Pb/s cable

Based on the mass production of 2CF, we estimated a transmission capacity based on ref. [13]. Figure 6 shows a system configuration in this evaluation. We assume a counter-propagation scheme and the signals of each core are divided by a FIFO then amplified by a conventional single-core EDFA. The amplified signals are combined by the FIFO device and input to 2CF. In this study, a span length and the number of 2CFs are fixed to 60 km and 48 (or 48 core-pair), respectively.

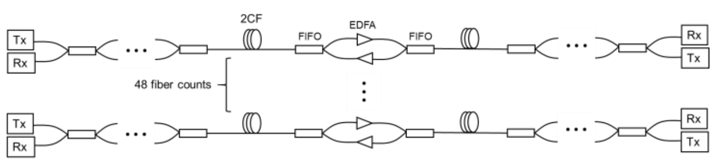

Fig.6. System configuration

Optical characteristics of 2CF are summarized in Tab.1. From the mass production result of counter-propagation XT of -50 dB at 100 km in Fig. 3, we converted it to -57 dB at 60 km. System parameters are also listed in Tab.2. We assumed that signal bandwidth was 4.8 THz (96 GBaud, 50 channels per fiber core). We assumed a 48-count 2CF SDM cable system having a power supply limitation with a supply voltage from power feeding equipment (PFE) to be 18 kV and direct current resistance (DCR) of cable to be 0.8 Ω/km. A FIFO insertion loss including a connection loss between FIFO and 2CF was considered to be 0.3 dB/device, a typical reported value [4], electrical-to-optical (E/O) conversion efficiency to be 2 %, and a noise figure of EDFA in submarine repeater to be 4.5 dB. The cable capacity can be estimated by the following equation [13].

$$C = 2N_{FP}M_{cores}N_{ch}B_{sym}\log_2\left(1+\frac{1}{\rho_{IP}}SNR\right) \quad (1)$$

where C is the cable capacity, N_{FP} is the number of FPs, M_{cores} is the number of cores per fiber, N_{ch} is the number of channels per fiber core, B_{sym} is the symbol rate, ρ_{IP} is a system margin from the Shannon limit, and SNR is signal to noise ratio.

Using the fiber characteristics and system parameters in Tab.1 and Tab.2, we estimated a cable capacity for the link length from 6,000 km to 9,000 km. Figure 7 shows the calculated link length dependence of the cable capacity. Channel power was optimized so that the SNR was maximized under the power supply limitation. From this calculation in Fig.7, we clarified that 8,400 km or shorter reach systems may have cable capacity of 1.0 Pb/s or beyond and 9,000-km reach system may have a capacity slightly lower than 1.0 Pb/s, 0.94 Pb/s. In terms of the device characteristics, lowering the fiber loss and insertion loss of the FIFO are possible ways for achieving 1.0 Pb/s, therefore, we evaluated the impact of these characteristics to the cable capacity. Figure 8 shows a relationship between the fiber loss and insertion loss of the FIFO in a 9,000-km reach system. The line shows a cable capacity of 1.0 Pb/s. The cable capacity of 1 Pb/s can be achieved by improving the fiber loss to 0.148 dB/km or the insertion loss of the FIFO 0.1 dB/device. There are some reports realizing 2CF with ≤ 0.150 dB/km [1-3], therefore, 1 Pb/s cable in over 9,000 km link would be also possible in the near future.

Tab. 1 Summary of 2CF mass production

Characteristic at 1550 nm	Value
Fiber loss	0.155 dB/km
Aeff	112 μm^2
XT, counter-propagation	-57 dB at 60 km
Chromatic dispersion	21 ps/nm/km

Tab. 2 Parameters used for capacity estimation of transatlantic cable

Parameters	Value
Link length	6,000-9,000 km
Span length	60 km
Baud rate	96 GBaud
Number of channels per core	50
Number of 2CF	48 (48-core-pair)
Power supply from PFE	18 kV
Cable DCR	0.8 Ω/km
E/O conversion efficiency	2 %
FIFO insertion loss	0.3 dB/device
Noise figure of EDFA	4.5 dB

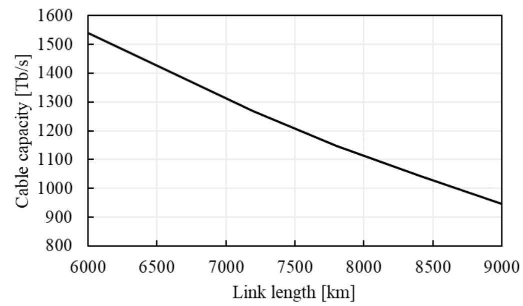

Fig.7: Estimated cable capacity in a 6,000 to 9,000 km link system

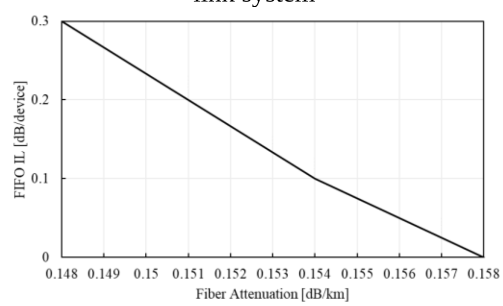

Fig.8: Relationship between fiber loss and insertion loss of FIFO for achieving 1.0 Pb/s in a 9,000 km system

4. Conclusion

We successfully demonstrated high optical performance of 2CF mass production with ultra-low loss of 0.155 dB/km and enlarged Aeff of 112 μm^2 for submarine cable application through a cumulative length around 10,000 km. In addition, we verified its feasibility for 1 Pb/s transmission capacity at a transatlantic distance. We clarified that the cable capacity more than 1 Pb/s can be achieved in a 8,400 km or less reach system. Furthermore, 1 Pb/s transmission can be realized even at 9,000-km reach system by improving the fiber loss and FIFO insertion loss which have been achieved in R&D. We believe that the mass production results of our 2CF will contribute to the realization of 1 Pb/s system for transoceanic transmission.

5. References

[1] T. Suganuma *et al*., in Proc. 49th European Conference on Optical Communications, paper Th.A.6.3 (2023).
[2] M. Tuggle *et al*., in Proc. 49th European Conference on Optical Communications, paper Th.A.6.2 (2023).
[3] B. Zhu *et al*., in Proc. 2024 Optical Fiber Communications Conference and Exhibition, paper Tu2E.2 (2024).
[4] V.I. Kopp *et al*., in Proc. 2022 Optical Fiber Communications Conference and Exhibition, paper Th1E.2 (2022).
[5] H. Takeshita *et al*., J. Lightwave Technol. **43**. 3, 980-988 (2023).
[6] E.F. Mateo *et al*., in Proc. 50th European Conference on Optical Communication, paper W1E.2 (2024).
[7] https://cloud.google.com/blog/products/infrastructure/delivering-multi-core-fiber-technology-in-subsea-cables?hl=en
[8] T. Hayashi *et al*., in Proc. 36th European Conference and Exhibition on Optical Communication, paper We.8.F.6 (2010).
[9] M. Koshiba *et al*., IEEE Photon. J. **4**. 5, 1987-1995, (2012).
[10] Y. Kawaguchi *et al*., in Proc. 2025 Optical Fiber Communications Conference and Exhibition, paper W4C.3 (2025).
[11] T. Hayashi *et al.*, Opt. Express, **20**, 26, B94-B103 (2012).
[12] T. Hayashi *et al*., in Proc. 2022 Optical Fiber Communications Conference and Exhibition, paper M1E.1 (2022).
[13] J.D. Downie *et al*., J. Lightwave Technol., **40**. 6, 1569-1578 (2022).