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Multicore fibre in cable and transmission trials

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Abstract *A prototype of submarine cable with 4-core uncoupled MCF was demonstrated. Through 5,350-km transmission trials using this MCF, no performance degradation due to the cabling process was observed. Also, reduction in the number of fan-in fan-outs in the transmission line contributed to improving transmission performance.*

Introduction

The demand for cable-system capacity expansion continues to increase due to the continuous shift to online services, which has been accelerated due to COVID-19, and the continuous increase in wireless device usage due to cutting-edge technologies such as 5G, the communication performance of which continues to improve. The conventional standard single mode single core fibre (SMSCF)-based technology is about to reach the theoretical limitation for capacity expansion [1]. The use of multicore fibre (MCF) is a good solution to increase capacity of transmission systems beyond this limitation to meet the demand of capacity expansion at a compound annual growth rate of 32% [2-5].

Toward practical use, terrestrial trials with cabled MCF have been conducted [6][7] because the transmission performance of MCF is supposed to differ from practical to laboratory-test environments. Tsuritani et al. [6] tested 0.92-km 200-fibre cable with 5-core uncoupled MCF (UC-MCF) with a 125-μm standard cladding diameter. They installed and tested it in various environments such as aerial poles, underground with conduits, outdoors with an innerduct, and indoors with closures. The measured difference in fibre loss between before and after cabling was less than 0.01 dB/km, which was equivalent to that of SMSCF. No frame loss of a 100-GbE signal was observed during 3.5-days over 4.6-km long transmission using the installed cable. Hayashi et al. [7] fabricated a 6.29-km MCF cable that accommodated 12 strands of 4-core randomly coupled MCF, four strands of 4-core UC-MCF, and two strands of 8-core UC-MCF. They installed it in a microduct with an inner diameter of 10 mm laid in an underground tunnel as a part of a field-trial optical network. The loss and inter-core crosstalk (IC-XT) of the UC-MCF was evaluated before and after cabling. They found that the impact of cabling and installation on the loss was negligible. Less than 2 dB of IC-XT-induced difference was observed throughout the evaluation using fan-in fan-out (FIFO).

There are additional requirements regarding space and energy limitations of submarine cable systems, which differ from terrestrial systems. The transmission distance over 1,000-km distance using optical repeaters is quite different from the trials described in the previous paragraph. The current design trend of cabling is to increase the number of fibre pairs (FPs) in a cable for capacity expansion to avoid optical-signal degradation due to the fibre non-linear

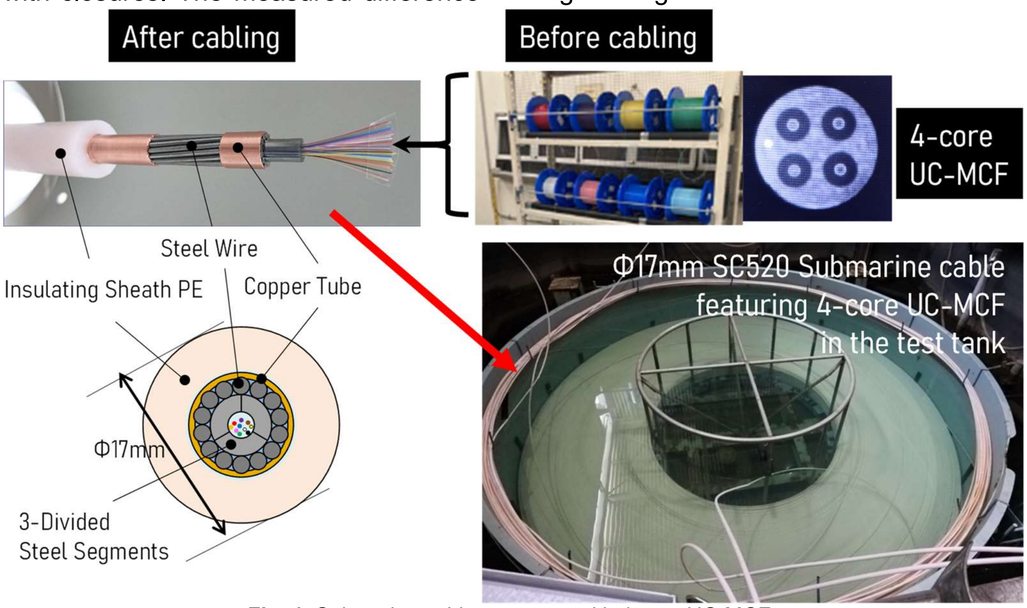

Fig. 1. Submarine cable prototype with 4-core UC-MCF

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effect [8]. The MCF in such submarine cable systems should also be tested.

In this paper, we report on the results from an experiment using a prototype 15.2-km-long submarine cable with MCF that accommodates 4-core UC-MCF, as shown in Fig. 1 [11]. Efficient amplification technology for an MCF-based transmission system is important for submarine cable systems as well as MCF and its cabling technology. We also clarify the benefit of integrating the amplifiers without using FIFO devices to connect to MCFs [8][11]-[13].

Effect of cabling process on 4-core UC-MCF properties

We selected an SC520-type submarine cable to accommodate the 4-core UC-MCF and fabricate our prototype [10][11]. Its unique feature of three-divided steel segments reduces changes on fibre properties between before and after cabling by overcoming the cabling-process-induced attenuation. The advantage of the light weight (LW) SC520 design of a 17-mm-cable outer diameter is 20% lower than that of the conventional cable design of 20-mm-cable outer diameter, though the fibre-mounting density of both is almost the same. This is helpful to increase the amount of cable that can be shipped and contribute to reducing the installation cost of the system. The LW SC520 cable can accommodate 32 fibres, i.e., 16 FPs, at maximum. The prototype was made of eight UC-4CFs and eight SCSMFs to compare the experimental results of UC-4CF with those of SCSMF.

We compared loss, chromatic dispersion (CD), and CD slope, and IC-XT before and after the cabling process by using the test results from the fibre vendor conducted at the factory during fibre incoming, after fibre rewinding, after copper tubing, and after polyethylene coating processes. The SC520 design was validated for SMF, and changes in fibre properties were negligible [10], except for IC-XT. The difference in IC-TX shown in Table 1 is assumed due to the core-positioning alignment accuracy when the MCF was spliced to the reference FIFO, which is indispensable for IC-XT measurement. This indicates that a standard IC-XT measurement method is needed, possibly without using FIFO or with a more accurate and stable MCF-connecting technique.

Table 1. Differences in properties before and after cabling

Loss	0.002 dB/km
CD (1550 nm)	-0.0007 ps/nm/km
CD slope (1550 nm)	-0.0005 ps/nm^2/km
IC-XT	-9 dB

Long-haul transmission trial using MCF in submarine cable

Figure 2 shows the experimental set-up of a loop transmission trial to validate the performance of the 4FPs of the 4-core MCF inside the 15.2-km-long submarine cable. The transmitted optical signal was 120 wavelength channels on the C-band (1528.775 to 1564.687 nm). Five 34.7-GBd polarization multiplexed quadrature shift keying (PM-QPSK) modulated channels were multiplexed with the loading channels shaped from amplified spontaneous (ASE). Since the receiver has an application specific integrated circuit (ASIC) that can be synchronized to the loop switch, which is shown as a 2 x 2 switch (SW) in Fig. 2, the bit error rate can be obtained in real time. This is useful to observe stability and analyse the effect of the fibre properties on transmitted signal quality. The wavelength of the PM-QPSK-modulated channels could be tuned on the whole C-band, and the Q-value was

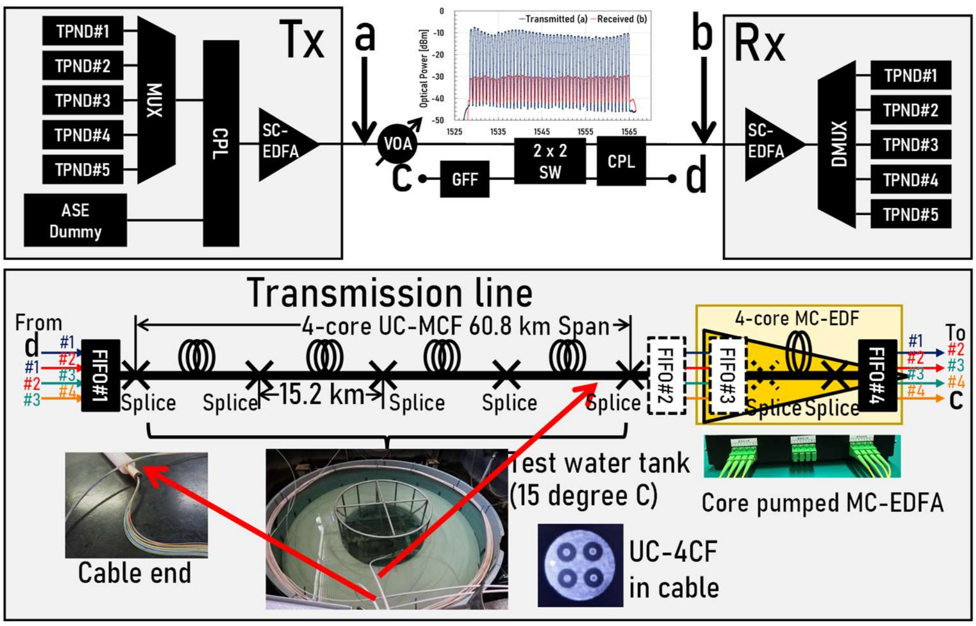

Fig. 2. Experimental-setup using prototype 4-core MCF submarine cable and 4-core MC-EDFA with and without FIFOs

obtained at the centre wavelengths (1529.07, 1537.40, 1546.52, 1555.75, and 1564.37 nm) of the five modulated channels to take the effect of the neighbour channels into account.

A 60.8-km span was achieved by splicing the four cabled 4-core MCF serially. The entire submarine cable was laid in 15°C water to avoid fibre-property fluctuations due to temperature variation, as shown in Fig. 2. The span loss was 13.3 dB, which includes loss by splicing, fibre transmission, and FIFO. The insertion loss and IC-XT of the FIFO per pair was 1.0 and -54 dB, respectively. The launch power was set to -4.5 dBm/ch, which was low enough to avoid the fibre non-linear effect. The output power and gain of the multicore erbium doped fibre amplifier (MC-EDFA) was 16.3 dBm/core and 13.3 dB, respectively. Under these operation conditions, the noise figure of the MC-EDFA was minimum, i.e., 6.3 dB. The pump power was 640 mW/core. As shown in the in-set of Fig. 2, a gain flattening filter (GFF) was used at every four spans, i.e., once per loop, to equalize the received optical signal to noise ratio (OSNR).

The most interesting point is the difference in the Q-value of the 4-core MCF transmitted signal between before and after cabling. Figure 3 shows the measured Q-value difference as a cabling penalty, ΔQ_{cable}, at a signal wavelength of 1546.52 nm. The ΔQ_{cable} was less than 0.2 dB within a 5,350-km transmission distance. This suggests good stability of the 4-core MCF in the submarine cable since it is identical to the measured accuracy, which is independent of the transmission distance. Therefore, the penalty due to cable assembly can be ignored.

Figure 4 is the difference in Q-value when the FIFO and splice point ΔQ_{FIFO}, shown as the dashed line in Fig. 2, was removed. The observed 0.6 dB of ΔQ_{FIFO} is thought due to the improvement in the signal-to-noise ratio (SNR) because it well matches the calculated Q-value improvement when the MC-EDFA gain was reduced due to the reduction in transmission loss. Considering the total amount of IC-XT was as small as -25 dB, the effect of IC-XT is assumed to be small [14]. Toward cable capacity expansion, the effectiveness of the reduction in the number of FIFOs has been shown experimentally.

To distinguish experimentally which effect, IC-XT or insertion loss, was dominant in Q-value improvement due to the removal of FIFOs, we changed the direction of signal transmission to bidirectional using the cabled 4-core UC-MCF with all the FIFOs, as shown in Fig. 5. The Q-value difference between bidirectional and unidirectional transmission $\Delta Q_{direction}$ was less than ±0.1 dB. Therefore, the improvement in ΔQ_{FIFO} is assumed to be OSNR dominant due to the reduction in total transmission loss.

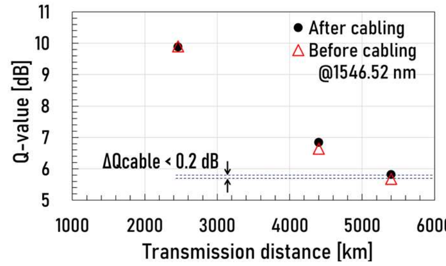

Fig. 3. Measured Q-value of 4-core UC-MCF transmitted signal before and after cabling

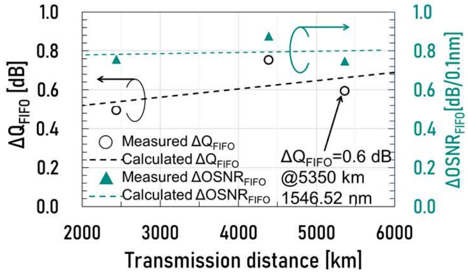

Fig. 4. Effect of reduction in number of FIFO and UC-MCF splice points on Q-value and OSNR

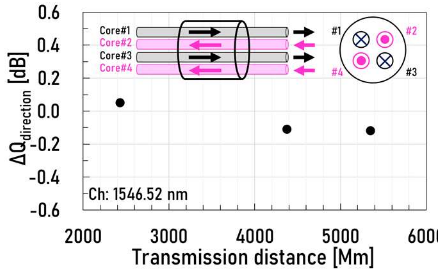

Fig. 5. Difference in Q-value between unidirectional and bidirectional transmission using cabled 4-core UC-MCF

Conclusions

A transmission trial of submarine cable with 4-core UC-MCF was reported. Throughout the trial, the performance degradation of the 4-core UC-MCF due to the cabling process was found to be negligible. The feasibility of improving transmission performance by reducing the number of FIFOs was also shown experimentally.

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References

[1] P. J. Winzer and D. T. Neilson, “From scaling disparities to integrated parallelism: A decathlon for adecade”, IEEE Journal of Lightwave Technology, vol. 35, no. 5, pp. 1099–1115 (2017)

[2] Submarine Telecoms Industry Report Issue 8, Submarine Telecoms Forum ,.available: https://issuu.com/subtelforum/docs/stf_industry_report_issue_8

[3] A. N. Pilipetskii and G. Mohs, “Technology Evolution and Capacity Growth in Undersea Cable”, OSA Optical Fiber Communication conference, March 8-12, San Diego (U.S.), W4E.2 (2020)

[4] H. Takahashi, D. Soma and T. Tsuritani, “Promising Technologies for Future Submarine Cable Systems”, 25th Optoelectronics and Communications Conference, October 4-8, Taipei (Taiwan), T3-3.2 (2020)

[5] T. Matsui, T. Kobayashi, h. Kawahara, E. L. T. de Gabory, T. Nagashima, T. Nakanishi, S. Saitoh, Y. Amma, K. Maeda, S. Arai, R. Nagase, Y. Albe, S. Aozasa, Y. Wakayama, H. Takeshita, T. Tsuritani, H. Ono, T. Sakamoto, I. Morita, Y. Miyamoto, and K. Nakajima, “118.5 Tbit/s transmission over 316 lm-long multi-core fiber with standard cladding diameter”, 24th Optoelectronics and Communications Conference, July 3-7, Fukuoka (Japan), WC2-2 (2017)

[6] T. Tsuritani, D. Soma, Y. Wakayama, Y. Miyagawa, M. Takahashi, I. Morita, K. Maeda, K. Kawasaki, T. Matsuura, M. Tsukamoto and R. Sugizaki, “Field Test of Installed High-Density Optical Fiber Cable with Multi-Core Fibers toward Practical Deployment”, OSA Optical Fiber Communication conference, March 3-7, San Diego (U.S.), M3J.4 (2019)R. Dar et al., "Submarine Cable Cost Reduction Through Massive SDM," 43rd European Conference on Optical Communications, September 17-21, Gothenburg (Sweden), Tu.1.E.5 (2017)

[7] T. Hayashi, T. Nagashima, T. Nakanishi, T. Morishima, R Kawawada, A. Mecozzi and C. Antonelli “Field-Deployed Multi-Core Fiber Testbed”, 24th Optoelectronics and Communications Conference, July 3-7, Fukuoka (Japan), Postdeadline papers, PDP3 (2019)

[8] J. D. Downie, X. Liang, and S. Makovejs, “Examining the Case for Multicore Fibers in Submarine Cable Systems Based on Fiber Count Limits”, Journal of Selected Topics in Quantum Electronics, Vol. 26, No. 4, July / August (2020)

[9] H. Takeshita, K. Nakamura, Y. Matsuo, T. Inoue, D. Masuda, T. Hiwatashi, K. Hosokawa, Y. Inada, and E. L. T. de Gabory, “First Demonstration of Uncoupled 4-Core Multicore Fiber in a Submarine Cable Prototype with Integrated Multicore EDFA”, OSA Optical Fiber Communication conference, March 6-10, San Diego (U.S.), paper M4B.1 (2022)

[10] M. Kobiki, H. Hayashi, J. C. Aquino, D. Masuda and S. Fujihara, “Latest High Fiber Count Submarine Cable”, 24th Optoelectronics and Communications Conference, July 3-7, Fukuoka (Japan), WC2-2 (2019)

[11] H. Takeshita, K. Nakamura, Y. Matsuo, T. Inoue, D. Masuda, T. Hiwatashi, K. Hosokawa, Y. Inada, and E. L. T. de Gabory, “First Demonstration of Uncoupled 4-core Multicore Fiber In a Submarine Cable Prototype with Integrated Multicore EDFA”, OSA Optical Fiber Communications Conference, March 6-10, Los Angeles (U.S.), M4B.1 (2022)

[12] M. Mazur, L. Dallachiesa, N. K. Fontaine, R. Ryf, E. Borjeson, H. Chen, H. Sakuma, T. Ohtsuka, T. Hayashi, T. Hasegawa, H. Tazawa, D. T. Neilson, and P. L. Edefors, “Real-Time Transmission over 2x55 km All 7-Core Coupled-Core Multi-Core Fiber Link”, , OSA Optical Fiber Communication conference, March 6-10, San Diego (U.S.), PDP paper Th4A.1 (2022)

[13] Y. Wakayama, N. Yoshikane, and T. Tsuritani, “FIFO-less Core-pump Combiner for Multicore Fiber Amplifier”, OSA Optical Fiber Communications Conference, June 6-10, Virtal, M3D.3 (2021)

[14] P. J. Winzer, A. H. Gnauck, A. Konczykowska, F. Jorge and J.-Y. Dupuy, "Penalties from in-band crosstalk for advanced optical modulation formats," 37th European Conference on Optical Communications, September 18-22, Geneva (Switzerland), paper Tu.5.B.7 (2011)