First ≤0.15-dB/km Uncoupled 2-Core Fibre for Transoceanic Cable

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Abstract *We realized uncoupled two-core-fibre having record-low loss of 0.149dB/km and 0.152dB/km for each core with negligibly small counter-propagating crosstalk of -56dB, which enables transmission capacity for transoceanic subsea system to be doubled without significant penalties compared to a single-core-fibre. ©2023 The Authors.*

Introduction

Space division multiplexing (SDM) technology is a leading candidate for next-generation optical fibre transmission technology. SDM technology using multi-core fibre (MCF) is the most effective way to increase submarine cable transmission capacity while controlling installation costs, especially in long-distance submarine systems, because it can increase cable capacity without increasing the number of fibres in a cable [1,2].

As the fibre count is approaching the limit that the current submarine cable can accommodate, multi-core fibres (MCFs) are gaining greater interest because of their scalability that they can accommodate 2 to 19 cores in the standard 125 μm diameter cladding [3-8]. However, as the number of cores to be accommodated in a fibre is increased, there are many challenges to be overcome for practical use including the low-loss MCF splicing, identification of respective cores, limitation of power supply for amplification, realization of multi-core amplifiers, introduction of a high-order MIMO (Multiple Input Multiple Output) signal processing.

Therefore, uncoupled 2-core-fibre (2CF) applied the configuration of asymmetric cores position [7] is a promising candidate as the next new fibre for submarine cables. This is because the 2CF can increase the transmission capacity by a factor of two compared to a single-core-fibre (SCF) with applying an existing single-core amplifier and signal processor by simply adding fan-in/fan-out devices (FIFO) for branching two-cores in a 2CF into two SCFs.

In this work, we present realization of 2CF with transmission loss of 0.149 dB/km and 0.152 dB/km for each of two cores, the lowest among reported MCFs to the best of our knowledge. The fabricated 2CF also has negligibly small counter-propagating inter-core cross-talk [XT] of -56 dB at 100 km.

To estimate the applicability of the 2CF to a high-capacity transoceanic submarine cable system, we compare its SNR penalty with that of a low-loss SCF, and show that fabricated 2CF will enable the transmission capacity to be doubled without significant penalties compared to SCF.

Fiber design

Fabricated 2CF was applied pure silica cores to realize low transmission loss, in which a low index region in-between two cores in order to suppress the XT. The 2CF also has configuration of asymmetric cores position with respect to the fibre centre, enabling marker-free identification of cores and polarity-free fibre end management [7], as shown in Figs. 1 and 2. Since MCFs have multiple cores, connection polarity management may result in complexity for handling at fibre, cable manufacturing processes, and possibility of wrong core-to-core connections at cable deployment and repair works. On the other hand, the present 2CF is free from this polarity issue because both ends have the same mirror-

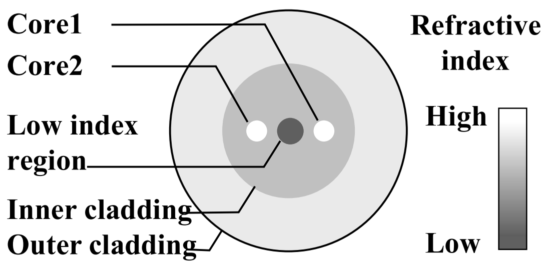

Fig. 1: Schematic structure of 2-core fiber (2CF).

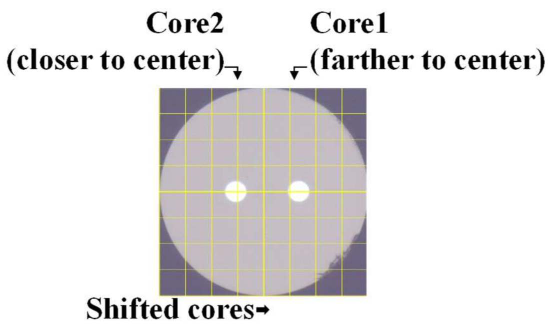

Fig. 2: Cross section of 2-core fibre (2CF).

symmetric core layout, which enables to connect 2CF between either end [7,9]. Hereinafter, the core farther from the fibre centre is referred to as Core 1, and the closer is Core 2.

Fiber characteristics

Tab. 1 shows optical characteristics of fabricated 2CF. The counter-propagating XT is as lows as -56 dB at 100 km on a shipping spool. Effective areas (A_{eff}) of respect cores are moderate values, 114 and 111 μm^2, equivalent to those of single-core submarine fibres for today's high-capacity transoceanic cable applications. Optical characteristics such as mode field diameter (MFD), chromatic dispersion (CD), dispersion slope, polarization mode dispersion (PMD), cable cutoff wavelength, and Macro bending loss are compliant with ITU-T recommendation G.654.B [10].

Thanks to the low-loss silica core technology developed for SCFs, both cores have low losses of 0.149 and 0.152 dB/km at a wavelength of 1550 nm, respectively, have been achieved as its spectra shown in Fig. 3. The transmission loss of 0.149 dB/km is equivalent to that of a single-core submarine fibre, and to the best of our knowledge, the lowest amongst reported various low-loss MCFs including uncoupled 2-core fibre [7], uncoupled 4-core fibre [4], and coupled 4-core fibre [6].

Tab. 1: Optical characteristics of 2CF at 1550nm

Item[Unit]	Value	
	Core1	Core2
Counter-propagating XT on shipping spool [dB at 100km]	-56	
Co-propagating XT on shipping spool [dB at 100km]	-32	
Transmission loss [dB/km]	0.152	0.149
MFD [μm]	11.2	11.5
Effective area [μm^2]	110	111
CD [ps/nm/km]	21.1	20.9
Dispersion slope [ps/nm^2/km]	0.058	0.059
PMD [ps/rkm]	0.08	0.06
Cable cutoff wavelength [nm]	1507	1413
R30mm Macro bending loss at 1625nm [dB/100t]	<<0.1	<<0.1

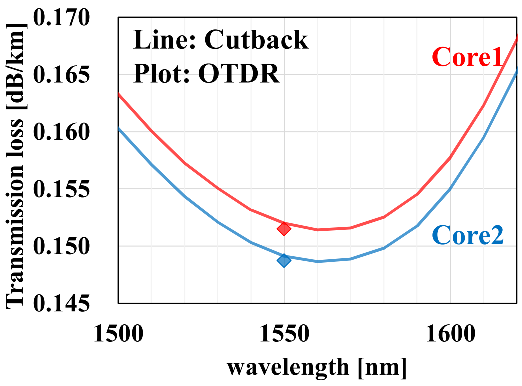

Fig. 3: Transmission loss spectra of 2CF

System performance

Transmission performance of the 2CF system is compared with that of the SCF system, assuming that the 2CF system has FIFOs in repeaters and uses the same EDFA, transmitter (Tx) and receiver as those for SCF as schematically shown in Fig.4. The performance of 2CF transmission systems can be estimated in terms of SNR (SNR_{2CF}) that takes span XT into account [11] in addition to SNR without XT that is composed of ASE noise ($\mathrm{SNR}_{\mathrm{ASE}}^{-1}$) and nonlinear impairment ($\mathrm{SNR}_{\mathrm{NL}}^{-1}$) [12]. Thus, we obtain

$$\mathrm{SNR}_{2\mathrm{CF}}^{-1} = \mathrm{SNR}_{\mathrm{ASE}}^{-1} + \mathrm{XT} + \mathrm{SNR}_{\mathrm{NL}}^{-1}, \quad (1)$$

$$\mathrm{SNR}_{\mathrm{ASE}}^{-1} = N_{\mathrm{span}} \cdot h\nu B \cdot \mathrm{NF} \cdot 10^{0.1 \cdot \alpha_{\mathrm{span}}} / P_{\mathrm{sig}}, \quad (2)$$

$$\alpha_{\mathrm{span}} = \alpha_{\mathrm{fiber}} \cdot L_{\mathrm{span}} + 2\alpha_{\mathrm{splice}}, \quad (3)$$

where h, ν, B, NF, α_{span}, P_{sig}, α_{fiber}, L_{span} and α_{splice} represent Planck constant, signal frequency (193.5 THz), amplifier bandwidth (4.5 THz), amplifier noise figure (5 dB), span loss, signal power (+17 dBm), fibre loss coefficient, span length and the loss due to the splice and FIFO for 2CF at an end of span, respectively.

Then, we evaluated the SNR penalty (ΔSNR) for 2CF compared to SCF defined as

$$\Delta\mathrm{SNR} = \mathrm{SNR}_{\mathrm{SCF}} / \mathrm{SNR}_{2\mathrm{CF}}, \quad (4)$$

ignoring nonlinear noise in order to simplify the discussion. We assumed a transmission loss of SCF as typical value used for current transoceanic systems, 0.150 dB/km. We also

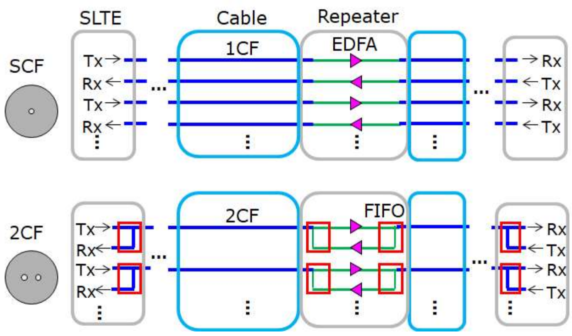

Fig. 4: Schematic views of SCF and 2CF systems

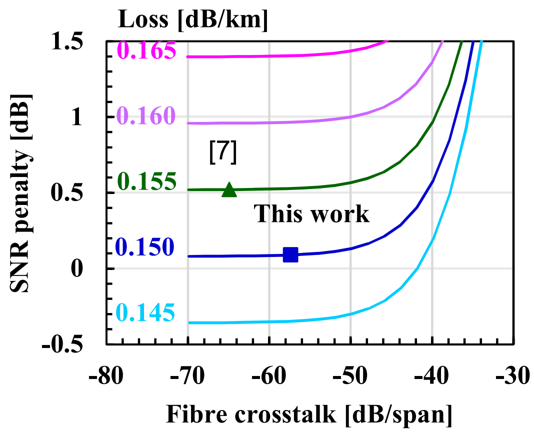

Fig. 5: SNR penalty of 2CF system compared to the reference SCF (0.150dB/km) system

assumed 2% shorter span length for 2CF than SCF because of 0.15 dB/device loss by FIFO [13]. The splice loss of 2CF with FIFO is assumed to be 0.1 dB per splice [7], the same loss with which is assumed as the splice loss of SCF with repeater. Calculated ΔSNR as a function of fibre XT considering 2CF transmission loss and FIFO insertion loss is shown in Fig. 5. Nonlinear length dependence of counter-propagating crosstalk is accounted for using Eq. (16) in Ref. [14]. As found in Fig.5, XT of around -50 dB per span or lower has negligibly small ΔSNR < 0.1 dB, but higher than -50 dB per span, ΔSNR increases significantly. As shown in Tab. 1, 2CF in this work has very low XT of -56 dB at 100km (-57 dB per 88 km span), and therefore, ΔSNR resulting from XT found to be ignored. Thanks to realization of 2CF loss equivalent to SCF by this work, calculated ΔSNR was as small as 0.1 dB that results from FIFO insertion loss (0.15 dB), significant improvement from the previous work in [7], 0.5 dB.

Even ΔSNR of 2CF was improved to 0.1 dB, it would make system performance significantly poorer, and finally, we estimated influence of ΔSNR to span length of transatlantic submarine system configuration. If the span length to be shorter in order to achieve required system performance, the numbers of repeater comes to be larger and makes total system cost higher. In this estimation, we assumed transmission distance of 7,200km and the span length of SCF system as 90 km, and calculated the span length of 2CF system to have the same system performance or fibre figure-of-merit [12]. As shown in Tab. 3, the calculated span length of 2CF system was 87.8 km and the numbers of submarine repeater for 2CF system was 82, only two spans more than the SCF system. Hence it will be able to conclude that 2CF in this work should be able to double the transmission capacity per a submarine cable without significant performance penalty.

Tab. 3: Comparison of span length and numbers of repeaters between SCF and 2CF.

	SCF	2CF
Distance [km]	7,200	
Span length [km]	90	88
N. of repeaters	80	82
Fibre loss [dB/km]	0.150	0.150
FIFO insertion loss [dB]	None	0.15
Splice loss to repeater [dB]	0.1	0.1
XT [dB/span]	None	-57

Conclusion

We demonstrated the uncoupled 2CF with low transmission loss of ≤ 0.15 dB/km and low XT of -56 dB at 100km as a next-generation fiber for submarine cables. In addition to these optical characteristics, the present 2CF is very practical due to marker-free simple core identification scheme, and the polarity-free fibre end management for connection.

Furthermore, the performance of a submarine system using this fiber is evaluated in comparison with conventional SCFs. While 0.15 dB/device loss by FIFO affects system performance, the influence is as small as 2% shorter span length and 0.1 dB SNR penalty because of the present 2CF's low loss and low XT. This extra repeater cost and penalty should be acceptable for enabling doubling the transmission capacity without increasing the cable size.

Some of previous research raised concern about the system cost advantages of using MCF for submarine cables with assuming significantly higher loss for MCF than that of SCFs [15]. However, the present low-loss 2CF should provide a solution for resolving those concern and adopting MCF for submarine systems.

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