Crosstalk Characteristics of Two Core Fiber Submarine Cables

Yuki Kawaguchi*, Hirotaka Sakuma*, Tetsuya Haruna*, Tetsuya Hayashi*, Hideki Yamaguhi*, Masaaki Hirano*, Takemi Hasegawa*, Keisuke Yasuhara**, Juan Carlos Aquino**, and Daishi Masuda**

* Sumitomo Electric Industries, Ltd., 1, Taya-cho, Sakae-ku 244-8588 Yokohama, Japan.
** OCC Corporation, 1-105-2, Hibiki-machi, Wakamatsu-ku 808-0021 Kitakyushu, Japan

Abstract

We demonstrated the XT characteristics of submarine two-core fiber cables. The cabled fiber XT is improved by 30 dB compared to a spooled fiber. The measured cables' XTs are low enough to suppress SNR degradation.

I. Introduction

Spatial division multiplexing (SDM) is now the most promising way to increase transmission capacity of a submarine cable. Two-core fiber (2CF) is going to be introduced to the next generation of spatial division multiplexing in submarine cables [1], and the 2CF was also successfully developed for mass-production [2]. One of the most important optical characteristics of uncoupled multi-core fibers (MCFs), including 2CFs, is inter-core crosstalk (XT) because high XT causes additional noise and consequently degrades the system SNR. A submarine cable installing 2CF with slightly different indices (heterogeneous core) was manufactured and XTs of the 2CF before and after cabling were measured [3]. The cabled fiber was found to have 12 dB lower co-propagation XT than that of uncabled one. However, the measured cabled fiber XT was almost same as a XT of FIFOs spliced to 2CF, so the measurement was not accurate, we concluded.

In this paper, we find the XT of cabled 2CF is improved by around 30 dB/km compared to an uncabled, spooled one with evaluating longitudinally accumulated XT measured by OTDR method. We also find that FIFO XT is dominant in the measured XTs of the cable.

II. XTs of Spooled and Submarine Cabled 2CF

MCF with a heterogeneous core configuration is known as an effective design for preventing XT degradation in submarine cables, because its XT decreases as the bending radius increases [3-5]. We manufactured 2CF having heterogeneous core 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. Figure 1 shows the length dependence of the co-propagation XT (XT_{co}) and counter-propagation XT ($XT_{counter}$) of uncabled 2CF wounded on a spool with an inner diameter of 168 mm. Plots and lines correspond to the measured and calculated results, respectively. The $XT_{counter}$ was calculated using the following equation [6],

$$XT_{counter} = XT_{co}\frac{S\alpha_R}{\alpha}\left[\frac{\sinh(\alpha L)}{\alpha L} - \exp(-\alpha L)\right] \tag{1}$$

where S, α_R, α and L are the proportion of backward Rayleigh scattering component, Rayleigh scattering loss coefficient, fiber transmission loss, and fiber length, respectively. Here, using the signal wavelength of λ and fiber refractive index of n, S can be expressed as,

$$S \approx \frac{3\lambda^2}{8\pi n^2 A_{eff}} \tag{2}$$

As shown in fig. 1, the measured and calculated XTs are in close agreement with each other; $XT_{counter}$ was 24 dB lower than XT_{co} at 90 km.

Utilizing this 2CF, we manufactured a 17 mm diameter commercial light weight submarine cable shown in fig. 2 that can support up to 32 and 48 fibers with 250 μm and 200 μm diameters, respectively. Notably, the 3-divided steel segments design has proved to not affect fiber attenuation caused by the cabling process [7]. Figure 3 shows length dependence of the cabled XT_{co} and $XT_{counter}$. As expected for the heterogeneous core design, XTs of the cable were improved from uncabled 2CF spooled on a bobbin, by around 17 dB and 12 dB for co- and counter-propagation at 90 km, respectively. In fig. 3, calculated XTs using equation (1) with XT_{co} at 90 km of -46 dB are also shown as lines, which were not in agreement with measurements. In addition, independent with the length, the measured XTs_{co} show almost constant value around -46 dB that was equivalent to a XT of FIFOs (XT_{FIFO}), concatenated to 2CF for XT measurement. In order to clarify improvement of XT of 2CF itself by the cabling, it is necessary to examine the impact of FIFOs.

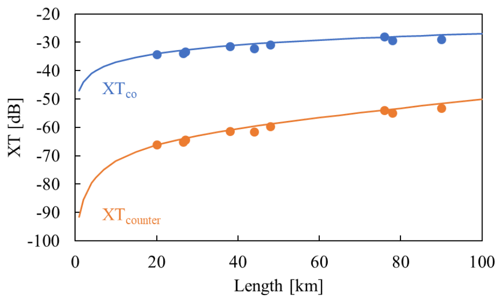

Fig. 1. Length dependence of the XTs of a spooled fiber.

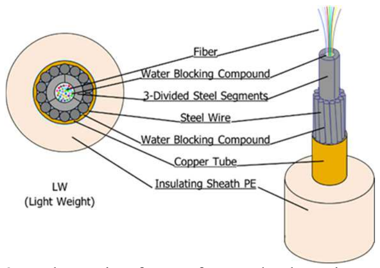

Fig. 2. Schematic of manufactured submarine cable.

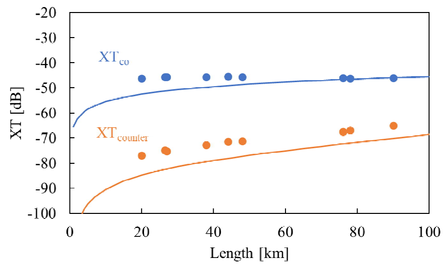

Fig. 3. Length dependence of the XTs of the submarine cable.

III. Impact of FIFOs on XT Measurement

Considering FIFOs connected at the input and output ends of 2CF, total XTs in co-propagation ($XT_{co,total}$) and counter-propagation ($XT_{counter,total}$) can be expressed as,

$$XT_{co,total} = XT_{co,fiber} + 2XT_{FIFO} \qquad (3),$$

$$XT_{counter,total} = XT_{counter,fiber} + 2XT_{FIFO}\frac{S\alpha_R}{\alpha}\sinh(\alpha L) \qquad (4),$$

where $XT_{co,fiber}$ and $XT_{counter,fiber}$ are XTs of the 2CF. In order to evaluate the $XT_{co,fiber}$ in the cable, we measured the XT using a single channel OTDR method [8]. Figure 4 shows a close view of the measured OTDR trace. From the slope of the trace, we estimated the $XT_{co,fiber}$ of the cable as 2.0x10^{-8}/km, equivalent to -77 dB at 1 km, that was around 30 dB lower than the uncabled 2CF. In the OTDR trace at lengths less than 10 km, we assume the measurement was not accurate due to an influence of an OTDR pulse tail. Then we calculated XTs using eqs. (3) and (4) with $XT_{co,fiber}$ of -77 dB at 1 km and XT_{FIFO} of -47 dB. Figure 5 shows length dependency of the XT_{co} and $XT_{counter}$. $XT_{co,FIFO}$ and $XT_{counter,FIFO}$ are XTs from FIFOs, which correspond to the second term on the right side of the eqs. (3) and (4), respectively. As seen from fig. 5, the measured XTs are agreed with the calculated XTs. XTs at 90 km are summarized in table 1. XT_{co} and $XT_{counter}$ of the cabled 2CF itself is around 30 dB lower than uncabled one.

Table 1. XTs at 90 km

	Uncabled fiber (measured)	Cable (measured)	XT from FIFO	Cabled fiber (estimated, w/o FIFO)
Co-propagation	-29 dB	-46 dB	-44 dB	-57 dB
Counter-propagation	-53 dB	-65 dB	-63 dB	-81 dB

Also, the XTs_{FIFO} are found to be dominant in the measured XTs of the cable. In order to suppress SNR penalty from XT noise to be 0.1 dB or less, it is known that a XT at a span shall be around -45 dB or less [9]. At 90 km, the measured XT_{co} and $XT_{counter}$ were -46 dB and -65 dB, and therefore, it can be safely concluded that a submarine transmission system based on these 2CF cables and FIFOs have negligibly low XT noise.

IV. Conclusions

We investigated the XT characteristics of uncoupled 2CF of uncabled/spooled condition and in submarine cable. Co-propagation XT of the cabled 2CF itself was estimated as -81 dB at 1 km that is 30 dB lower than uncabled one, and we found FIFO XT is dominant in the measured XTs of the cable. As a result, the submarine 2CF cables and FIFOs investigated here have low enough XT characteristics to realize 1 Pb/s cables.

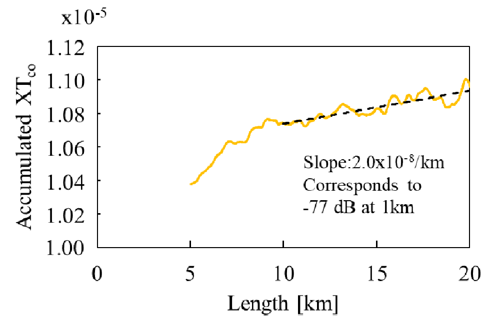

Fig. 4. Longitudinal dependence of XT_{co} of the cabled 2CF.

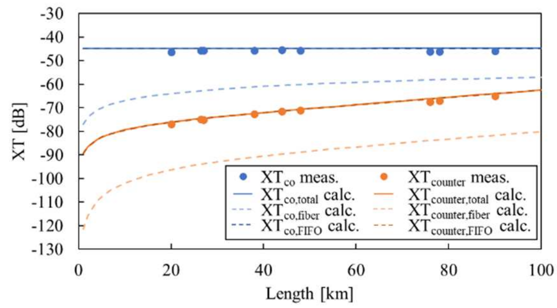

Fig. 5. Length dependence of the XTs of the submarine cable. Calculations are considered the XT of the FIFOs.

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