

200µm Diameter Fiber for SDM Submarine Networks: Cabling Performance and Record Transmission Result

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Abstract: 200µm-diameter fiber is analyzed for SDM systems where capacity is approaching fiber density limitations in standard cable designs. This fiber is fully characterized over a 15000km+ transmission line. This represents, to our knowledge, the first ever ultra-long-haul transmission with 200µm large effective-area fiber.

1. Introduction

The remarkable growth of subsea connectivity and capacity in recent years has stimulated the advent of the so-called SDM submarine technologies. This represents a subset of the more general SDM concept. It consists of the development of high fiber count (HFC) cables and pump-sharing repeaters to enable large capacity transoceanic system with lower cost-per-bit and lower watt-per-bit [1,2]. Submarine cables supporting 20+ fiber pairs (40+ fibers) are commercially available in 20mm (outer cable diameter) submarine cables with standard 250µm diameter fiber. However, the more standard 17mm cables can support around 32 fibers due to space limitations in the inner diameter of the cable. This maximum fiber density per unit area (fibers/mm^2) is required to preserve ultra-low attenuation and fiber integrity. To overcome this limitation, either a new (bigger) cable design or lower diameter fiber can be explored to increase the fiber density in standard cables. This second approach is preferable as it reduces the cable material cost and cable weight, which has a large impact in marine implementation. The reduction of fiber diameter represents an increase of fiber count of 1.5× which is very significant in SDM cables. 200µm differs from the standard 250µm fiber only in the thickness of the coating layer. This difference could have an impact in cabling performance, mechanical robustness (i.e. less protection from coating), or microbending loss (decrease in cushioning). These aspects must be carefully considered during the cabling evaluation. In this paper, we have evaluated the transmission performance of Corning® Vascade® EX2000 fiber with 200µm coating diameter, a nominal effective area (Aeff) of 115µm^2 and ultra-low attenuation of 0.152dB/km. This SDM fiber can be a crucial element to further increase the capacity of 17mm and 20mm cables towards 1Pb/s transoceanic capacity with 40+ FPs.

2. Evaluation of 200um fiber and cabling results

Description of the fiber

Fiber with moderately large (110-115µm^2) Aeff is a good candidate for submarine SDM systems due to its ~0.01dB/km lower attenuation and lower impact of Guided Acoustic Wave Brillouin Scattering (GAWBS) compared to 80µm^2 fiber. As such, for this experiment we used Vascade EX2000 fiber but with a 200um coating diameter instead of a more established 250um. This was achieved by reducing both the primary and secondary coating diameters of the Corning's proprietary CPC® coating system with its advantaged microbend and damage resistance performance. No changes were required to maintain ultra-low fiber attenuation in the finished cable with an average attenuation of 0.152dB/km. We did not observe any fiber attenuation penalty by reducing the coating diameter to 200µm. This is attributed to the unchanged glass structure and cladding diameter (125µm). Vascade EX2000 is Germania-free and has fluorine-doped cladding to achieve the required refractive index difference between the silica-core and the cladding. The spliced fiber spans for this experiment were measured to have an average mode field diameter of 12.0µm (corresponds to effective area of 113µm^2) at 1550nm wavelength, which is close to nominal values for Vascade EX2000 fiber. The typical dispersion was 20.2ps/nm-km at 1550nm and maximum cable cut-off wavelength was less than 1520nm. The combination of mode field diameter and dispersion serves to minimize microbending loss.

Cabling results with 48 fibers in 17mm-diameter submarine cable

A thinner coating layer of the fiber could allow more mechanical stress to be imparted through the coating to the glass. This stress could cause micro bending induced attenuation and degrade the performance of the fiber. Therefore, it is very important to evaluate the performance of the fiber after cabling and verify if the cabling process alters the performance of the fiber due to a reduced coating of the fibers. For that, 48 fibers were inserted in a 15km sample of standard 17mm submarine cable, OCC-SC530. After cabling, the attenuation values of twelve Vascade EX2000 fibers were measured and the results are shown in Fig. 1.

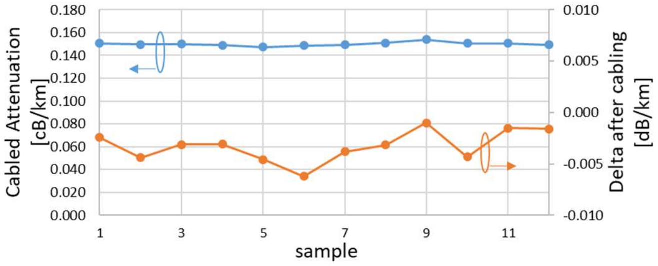

Fig. 1: Fiber attenuation results of Vascade EX2000 after cabling 48 fibers with 200um outer diameter into a standard 17mm submarine cable

The results show an average reduction of the attenuation after cabling of -0.0033dB/km. This proves that the cabling process does not affect the performance of the fiber even when the coating is reduced to 200um in a 48 fiber cable. This confirms that the reduced fiber coating still maintains suitable cushioning capability. Also, "Fiber Occupancy Ratio" (# of fibers per mm^2) is still maintained on better range due to smaller fiber diameter.

3. GAWBS measurement of 200µm fiber

Optical performance related to attenuation and Aeff is determined by the glass structure of the fiber, however GAWBS can also be affected by the coating [3]. We measured the GAWBS for a 40-km-long 200µm Vascade EX2000 fiber and compared it with a 250µm Vascade EX2000 fiber of same length. Measurement set up is shown in Fig. 2(a). A coherent, homodyne setup is used with a integrated tunable laser assembly (ITLA) tuned to 1550 nm split into the local oscillator (LO) and the input of the fiber under test (FUT). After the FUT, CW light carrying the GAWBS tones is amplified and the added ASE noise is filtered in multiple stages, resulting in 49 dB OSNR at the receiver. The receiver is a standard polarization-diversity coherent receiver with band-pass filters (BPFs) placed after the photodiodes. BPFs reject below 20 MHz to suppress the high carrier, and above 1 GHz to remove excess noise from ASE-ASE beating and prevent higher frequency noise folding back to the 1 GHz window. Received signal is sampled at 5 Gsa/sec using a 4-port real-time scope which measured simultaneously the GAWBS noise in both polarizations. A second ITLA 900 MHz away from the original carrier is added to the signal arm to calibrate the level of GAWBS peaks with respect to the original carrier which was rejected by the BPFs.

GAWBS noise is either created by the so called R0m acoustic modes which generate tones that are polarized along the carrier, or TR2m acoustic modes which generate unpolarized tones. Using polarization diversity coherent receiver we were able to separate the two contributions. Fig. 2(b) shows the power spectral density of polarized GAWBS noise for both 200µm and 250µm fibers. The spectra overlap almost perfectly, except for the two peaks below 100 MHz, which are narrower for the 200µm fiber. This can be attributed to the acoustic modes in this window experiencing less damping from the reduced coating which agrees well with prior research work reporting a stronger interaction of lower frequency modes with coating [4]. This suggests that the impact of thinner coating on the width of the tones and the overall noise power is neglible. Similar conclusions can be derived from the measurement of the unpolarized contribution to the GAWBS as shown in Fig. 2(c).

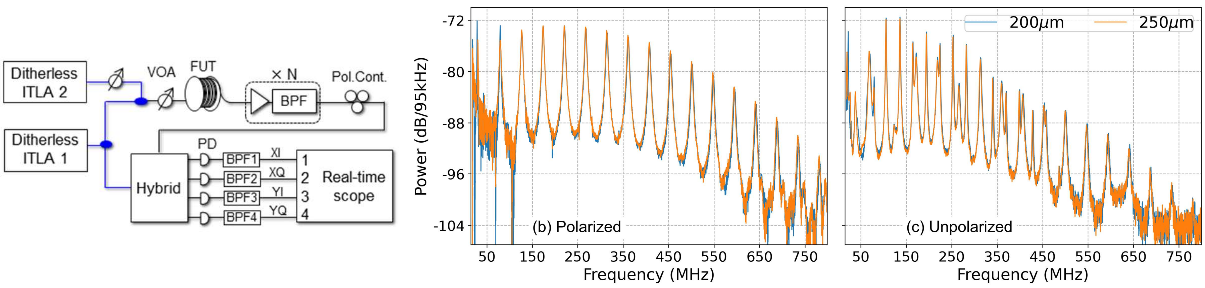

Fig. 2: (a) GAWBS measurement setup. Blue: polarization maintaining components. Measured polarized (b) and unpolarized (c) GAWBS spectra for 200µm (blue) and 250µm (yellow) fiber.

GAWBS limited SNR can be calculated by integrating the total noise under the GAWBS spectra. The final measured GAWBS coefficient was found to be γ_GAWBS=-29.7 ±0.2 dB/Mm, for both 200 µm and 250 µm Vascade EX2000 fibers.

3. 60+gbaud transmission over 18320km of an SDM submarine line design with 200µm fiber

The transmission line was set-up in a recirculating loop with the real-time channel operating in gated mode. The transmission loop consisted of 8 spans of Vascade EX2000 fiber. The fiber has an average attenuation of 0.152 dB/km and an effective area of 113 μm^2 . The span length is 85 km, which agrees with the SDM optimization shown in the previous section for voltage constrained systems. The amplifiers are set to operate at 18 dBm total power and 2 additional amplifiers are used to compensate for the loop switch losses and the WSS-based gain equalizer. Figure 3 shows the experimental set-up.

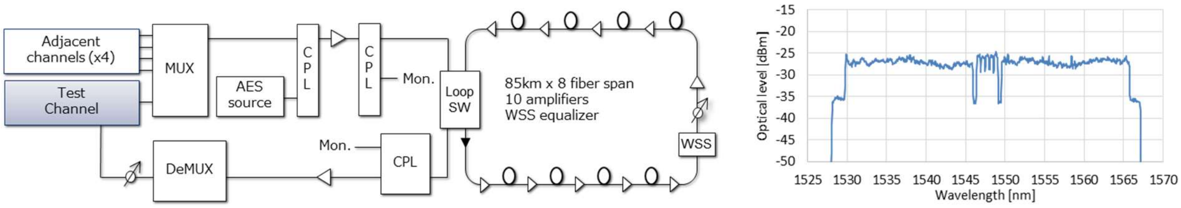

Fig. 3. Experimental set-up and received spectrum. The test channel was located at 1547.72 nm.

The test channel was transmitted in seven spectral locations covering the entire amplifier bandwidth. The remaining spectrum was loaded with broadband ASE. Together with the test channel, 4 additional adjacent channels were loaded next to the test channel to account for inter-channel interference effects. These adjacent channels are located at the same spacing and carry the same amount of output power compared to the test channel. Similarly, the transmission was tested at several spectral locations.

The channel consisted of 200G large baud-rate signals with a channel spacing of 75 GHz and an approximate filling ratio of 90%. This represents a spectral efficiency of 2.67 b/s/Hz. The modulation format, the operating baud-rate and the spectral shaping are optimized for maximum performance.

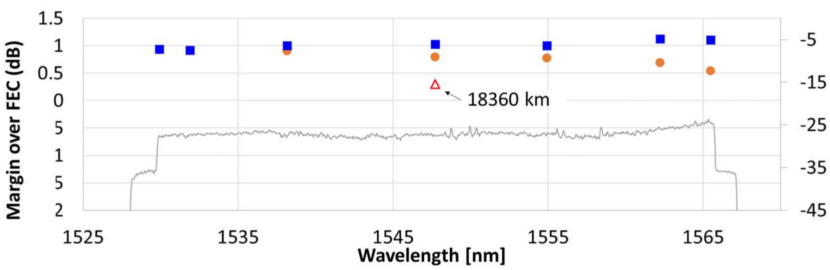

Fig. 4. Performance results after 17680 km transmission with 200G channels at 2.67 b/s/Hz. [Orange bullets] nominal channel power. [Blue squares] optimum pre-emphasis. The triangle indicates the performance at record 18630km.

The figures shows the results for both nominal channel power of -0.13dBm (in orange bullets) and at the optimum pre-emphasis (in blue squares). The nominal power corresponds to a fully loaded system of 60 ×200G carriers providing a maximum capacity of 12.0 Tb/s with around 1dB margin over the FEC limit. Additionally, the distance was further increased to 18630km with the transponder operation close to the FEC limit. To the best of our knowledge, this is the longest transmission reported with real-time 60+Gbaud signals.

Conclusion

200µm fiber with large effective area is verified for ultra-long haul transmission in next generation SDM submarine systems. Smaller form factor fibers are crucial to support further evolution of the SDM paradigm and to achieve the Petabit capacity in transoceanic networks.

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