Transmission of 81 channels at 40Gbit/s over a Transpacific-Distance Erbium-only Link, using PDM-BPSK Modulation, Coherent Detection, and a new large effective area fibre.

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Abstract:

Eighty-one channels spaced by 50GHz and modulated at 40Gbit/s are transmitted over 11520km, thanks to RZ PDM-BPSK modulation, coherent detection, and a new large effective area fibre.

Introduction

Within a given amplifier bandwidth, the capacity of an optical system is simply proportional to the information spectral density (ISD). The ISD of commercial undersea systems is expected to reach 0.4bit/s/Hz in the near future at 10Gbit/s (i.e. at 25GHz channel spacing). Besides any other cost-related issues, the introduction of 40Gbit/s channel rate is only attractive in terms of capacity if the ISD exceeds this value. Despite an impressive demonstration over 11,220km obtained with 100GHz-spaced channels [1], Alternate Polarization Return-to-Zero Differential-Phase Shift Keying (APol-RZDPSK) technologies at 40Gbit/s can hardly exceed 0.4bit/s/Hz ISD. Because of their narrower channel spectral width, Narrow-filtered Differential-Phase Shift Keying (DPSK) [2], RZ-Differential Quadrature Phase Shift Keying (RZ-DQPSK) modulation [3] and Polarization-Division Multiplexed (PDM) QPSK [4] technologies were all investigated as alternative options to meet 0.8bit/s/Hz ISD, but only DPSK could be transmitted over a transoceanic distance, namely 8,200km [2]. RZ PDM Binary Phase-Shift Keying (RZ PDM-BPSK) with differential detection is one last solution which has been proposed for 0.8bit/s/Hz ISD [5, 6, 7] at 40Gbit/s but, again, the reach was limited to less than 6,000km [6, 7].

Here, we propose to associate RZ PDM-BPSK with coherent detection at 0.8bit/s/Hz ISD, and a simplified submarine line using a single fibre [8]. This fiber was specifically designed with a large effective-area (A_{eff}~120µm²) and a low-loss (α~0.184dB/km).

Experimental Set-up

The test-bed depicted in Figure 1 involves eighty-one lasers spanning over a 50GHz frequency grid and split into two 100GHz-spaced sub-combs of odd and even channels. Each sub-comb is passed into a Mach Zehnder Modulator driven at 21.5Gbit/s, including 7% overhead for forward error-correction emulation, and fed with 2^{15}-1-bit pseudo-random words. The output light is sent into a pulse carver driven by a 21.5GHz sinusoidal clock, in order to generate 21Gbit/s RZ-BPSK optical data. These data are split into two copies, one of them being delayed by approximately 100 bits with respect to the other, before being recombined into a Polarization Beam Combiner (PBC), to yield 43Gbit/s RZ PDM-BPSK channels. The odd and even channels are then passed into low-speed (~1Hz) polarization scramblers and interleaved spectrally. The resulting multiplex is amplified by a booster and sent into a 640km-long recirculating loop, composed of eight 80km-long spans of Draka LongLine™. Standard, 980nm-pumped, single-stage, submarine Erbium-Doped Fibre Amplifiers (EDFAs) with 17dBm output power are used to compensate for each span loss. At the end of the loop, a Dynamic Channel Equalizer (DCE) equalizes channel power levels, while a ~1-4KHz loop polarization scrambler rotates the signal relative polarization state from one loop to the next (loop duration ~3ms). The PMD of our loop is estimated to be less than 1ps per round trip.

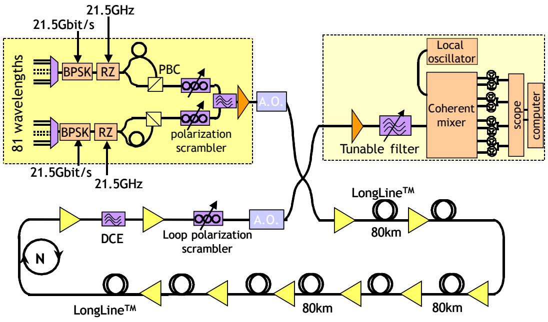

Figure 1: Experimental set-up of the 640km long recirculating loop (A.O. : Acousto-Optic switch)

At the receiver side, the signal is first amplified and then filtered by a 0.6nm-wide optical filter before being sent to the coherent receiver. A full description of this receiver was given in [9]. It uses digital signal processing for discriminating the phase/polarisation states but also for compensating the large cumulated chromatic dispersion (up to 230,000ps/nm). The absence of in-line dispersion compensation enables to fully take advantage of the fibre large effective area as compared to conventional submarine dispersion managed spans.

Experimental Results

Three distances are considered, 7680km, 8960km and 11,520km, respectively. At each distance and at each of the 81 wavelengths, two digitized waveforms of 4x2Msamples are recorded at two different trigger times, separated by a few seconds, and processed off-line on a computer. The bit-error rate (BER) is estimated after averaging over the two waveforms, namely over ~3.5 million bits, and converted into Q^2-factor, as shown in Fig. 2. With such long data streams, the number of counted errors already exceeds 120 errors when Q^2-factor gets lower than 12dB. We observe slightly better BERs in the upper part of the wavelength band than in the lower part (~1dB tilt). We attribute this trend to the poorer noise figure of the EDFAs and also to the slightly higher fibre attenuation in the lower part of the C-Band.

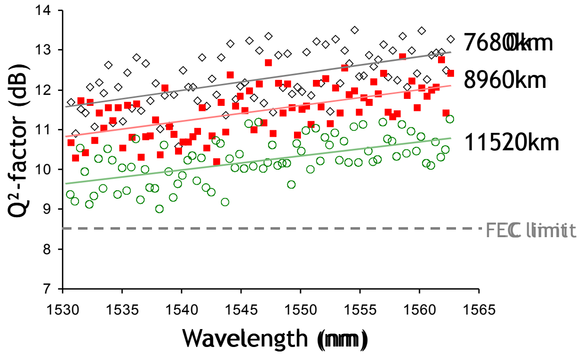

Figure 2 : Q² factor, from BER measurements, of 81 channels at 7,680km (open diamonds), 8,960km (red full squares) and 11,520km (circles)

The minimum, average and maximum Q^2 factors recorded over the 81 channels at each distance are plotted in Fig 3 as a function of transmission distance.

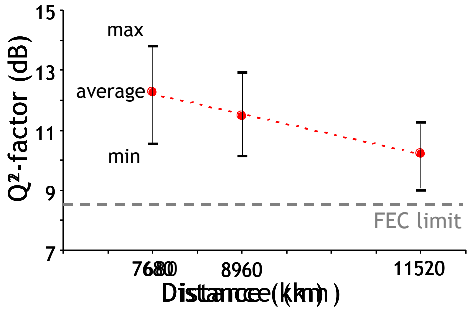

Figure 3 : Min, max and average Q²-factor measured on 81 channels versus propagation distance

Not surprisingly, a small reduction of performance can be noticed when distance grows. However, when moving from 7,680km to 11,520km (i.e by 1.75dB), the average Q^2 factor is reduced by no more than 2dB, i.e. almost in line with the OSNR reduction.

In order to evaluate the difficulty of sending extremely dense WDM multiplexes over long distances, the product of ISD times the transmission distance (D) is an interesting parameter. In Fig 4, we reported this product, extracted out of the most impressive experiments of this kind. It can be seen that the best past results never exceeded 6700bit/s/Hz.km. Our experiment demonstrates an unprecedented ISDxD product of 9200bit/s/Hz.km, a 38% increase compared to the previous record [10] obtained at 10Gbit/s by using DPSK and 15.4GHz channel spacing and a 40% increase compared to the previous record at 40Gbit/s, obtained by using DPSK and 50GHz channel spacing [2].

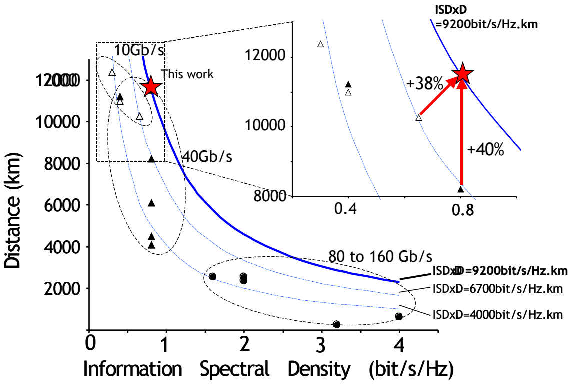

Figure 4 : selection of WDM transmission results (>0.8Tbit/s), distance versus information spectral density. Zoom is shown in inset.

Conclusion

Eighty-one 40Gbit/s WDM channels with 50GHz channel spacing have been transmitted over 11,520km by using a novel configuration of submarine line based on a single type of fibre with large positive dispersion, low loss and large effective area and PDM BPSK modulation scheme associated with coherent detection at the receiver side. This experiment sets a new information spectral density times distance product record at 9600bit/s/Hz.km.

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