2.38 Tb/s (16 x 160 Gb/s) WDM Transmission over 292 km of fiber with 100 km EDFA-spacing and No Raman Amplification

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Abstract *160-Gb/s WDM transmission over 100-km EDFA-span is presented, which is achieved without Raman amplification and proper dispersion management. This DQPSK and PolDM based system has eight times better tolerance to chromatic dispersion than ETDM system.*

Introduction

The combination of DQPSK with polarization division multiplex (PolDM) [1] quadruples the capacity of 40 Gb/s systems to 160 Gb/s, with ~8 times better tolerance to chromatic dispersion (CD) compared to ETDM systems. Besides increasing the total reach, EDFA span lengthening is also interesting as some EDFAs can be left out and cost is consequently reduced. In the 160 Gb/s per channel WDM experiment reported in [2], 75 km repeater spacing was reached. In the experiment that used DQPSK and PolDM to produce 160 Gb/s system, only a span distance of around 80 km was reported [1]. To date, there is no report showing the success of 160 Gb/s per channel WDM transmission beyond the mentioned span distances. In this paper we report 160 Gb/s per channel WDM transmission with ~100 km span length over a total of 292 km of fiber without Raman amplification or special dispersion management. To the best of our knowledge, this is for the first time that such achievement is reported.

Transmission setup

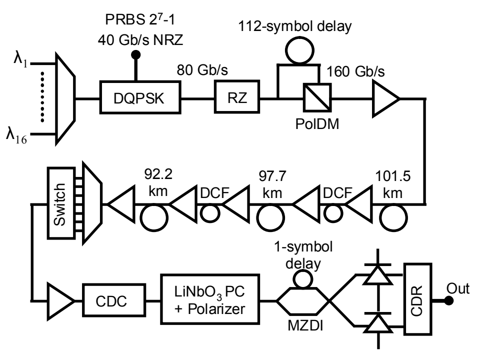

Fig. 1: Setup

The transmission setup is depicted in Fig. 1. At the transmitter, 16 equally polarized 100-GHz spaced WDM channels with optical frequencies from 192.2 THz (1559.79 nm) to 193.7 THz (1547.72 nm) were used. The linewidths of the lasers were in the range of 0.8 to 5.6 MHz. The 40 Gb/s NRZ data pattern was a 2^7-1 PRBS. A differentially quadrature phase shift keyed (DQPSK) signal was generated by combining two DPSK signals in a fiber Mach-Zehnder interferometer [1]. By using this technique, two (I and Q) uncorrelated DQPSK data streams were produced, and in the 100-GHz spaced WDM system, all WDM channels have at least one neighbour with different data pattern. Another dual-drive modulator driven at half the clock rate and biased at the transmission minimum carved ~13 ps long pulses and thereby generated the RZ-DQPSK signal. This signal was then splitted into 2 branches and recombined in Polarization Beam Combiner (PBC) to produce 160 Gb/s DQPSK PolDM signal [1].

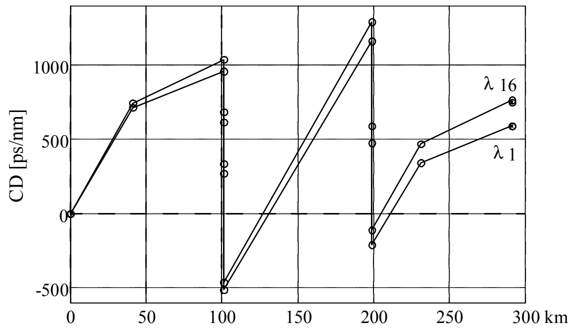

Fig. 2: Dispersion map

The 292 km long transmission line which consisted of SSMF and truewave RS (TWRS) NZDSF was arranged into only three spans. The first, 101.5 km long span contained 41.5 km of SSMF and 60 km of TWRS. 97.7 km SSMF was used as the second span. The third, 92.2 km long span consisted of 32.2 km of SSMF and 60 km of TWRS. In this setup, no dispersion pre-compensation was used. The spans exhibited losses of 22 dB, 23 dB and 21 dB, respectively. Between the spans, double-stage EDFAs were used to compensate for the span loss. Between the stages, dispersion-compensating fiber modules (DCM) were installed for dispersion compensation. The dispersion values of the DCMs at 1545 nm wavelength were -343 ps/nm (DCM-20), -684 ps/nm (DCM-40) and -780 ps/nm (DCM-47.5). All DCMs were of old type with only 43% SSMF slope compensation. In total, -2834 ps/nm of in-line dispersion compensation was used in this experiment. Due to the double-stage EDFA characteristics, we chose the span output (= received) powers between -18.5 dBm and -15 dBm per channel, and increased the launch powers to support long span transmission. The maximum launch power was +7dBm per WDM channel. To reduce nonlinearity, the input powers of all DCMs were fixed at -1 dBm per channel by using optical attenuators between the output of the first stage EDFA and the DCM input. In total the transmission line was about 292 km long. The dispersion map of this transmission is shown in Fig. 2.

At the receiver, the received WDM signal was optically preamplified and demultiplexed in a flat-top optical demultiplexer. The residual chromatic dispersion (CD) was compensated by a home made compensator. After CD compensation, one or the other polarization was selected and DQPSK signals were recovered.

Results and Discussion

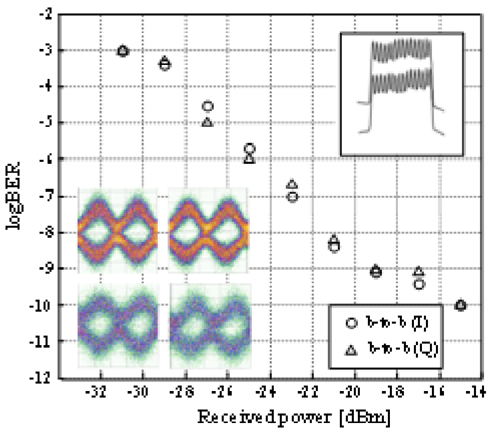

Fig. 3: Back-to-back receiver sensitivity of I and Q channels in one polarization. Inset: Bottom left - Eye diagrams back-to-back (top) and after 292 km (bottom) for I (left) and Q (right) quadratures; top right – spectrum of 16 WDM channels before (top) and after (bottom) transmission.

The back-to-back sensitivity of both I and Q quadratures of one polarization channel was measured on a midband WDM channel and is presented in Fig. 3. At a BER of 10^{-9}, sensitivity of around -19 dBm was obtained. At the FEC limit a sensitivity of as good as -31 dBm to -32 dBm was reached. The inset (top right) shows the 16 WDM channel before and after transmission. At the receiver, the OSNR was uniform for all channels. This is indicative that all channels experienced similar nonlinear phase noise. The residual dispersion slope after transmission and inline CD compensation, but before the receiver-based residual CD compensator, was about +13 ps/nm^2. The eye diagrams (bottom left) of both I and Q channels in one polarization, which were recorded after the third span, show a clear eye opening. The eye diagrams of the other polarization and the other WDM channels were similar.

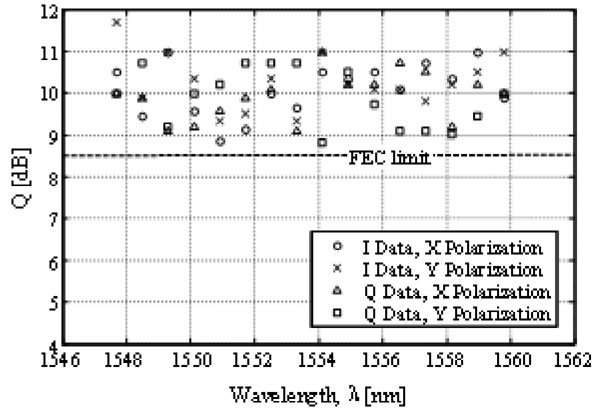

Fig. 4: Q factors of all WDM, quadrature and polarization channels after transmission.

In Fig. 4, the received Q factors for all polarizations, quadratures and WDM channels are presented. For performance assessment, we assume a third generation FEC that would bring better than 10^{-13} BER after correction when the Q factor is higher than 8.5 dB [3]. The BER was measured after 292 km and the corresponding Q factors were calculated. The best and worst Q factors were 11.7 dB and 8.7 dB respectively, all above the FEC limit. For our non-optimized link this result is considered satisfactory. A bitrate × span distance product of 16 (Tb/s)·km per wavelength was reached. Due to our available measurement setup we were not be able to include FEC overhead bits into the bitrate. We therefore consider the total transmitted bit rate to be only 40/43 of the aggregate 16×160 Gb/s bit rate, i.e. 2.38 Tb/s. In comparison to other 160 Gb/s WDM systems, the CD management for this system is much easier because of the higher CD tolerance.

Conclusions

We have demonstrated, for the first time, a 160 Gb/s per channel WDM transmission over ~100 km long spans, by using DQPSK in conjunction with polarization division multiplex. A channel bitrate × span distance of 16 (Tb/s)·km was achieved. To our knowledge this is the best reported value for 160 Gb/s per channel WDM systems. The unoptimized transmission link indicates that even longer spans can be reached when Raman amplification is used and appropriate dispersion management is implemented.

References

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