Reflective SOA re-modulated 20 Gbit/s RZ-DQPSK over distributed Raman amplified 80 km long reach PON link

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Abstract: An 80 km bidirectional Raman amplified long reach PON link has been demonstrated. A 20 Gbit/s RZ-DQPSK signal was transmitted downstream, ASK-remodulated at 1.25 Gbit/s by an RSOA and transmitted upstream in the same fiber. Both signals were detected error free without use of EDFAs.

OCIS codes: (060.2360) Fiber optics links and subsystems; (060.4250) Networks; (060.5060) phase modulation.

References and links

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1. Introduction

Fiber to the customer is very likely to be a major part of the next generation of optical networks, and already today this service is offered in many areas. Many of these systems use an architecture where electro-optic (EO) conversion takes place at the local exchange point between the end user and the link to the core network [1]. Avoiding this EO conversion is economically advantageous because of the reduction in equipment. Wavelength division multiplexing (WDM) followed by passive splitting has been suggested in [2]. Remodulation of the down-stream carrier for upstream transmission has been proposed in [3]. The advantage of distributed Raman amplification has been demonstrated in [4].

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In this paper, we propose and demonstrate a system for a bidirectional 80 km long reach PON link. The system consists of a distributed Raman amplified link in which a differential quaternary phase shift keyed (DQPSK) signal is transmitted downstream at 10 Gbaud/20 Gbit/s, ASK-remodulated at 1.25 Gbit/s with a reflective semiconductor optical amplifier (RSOA), and transmitted upstream through the same fiber. To our knowledge, this is the first demonstration of DQPSK in a bidirectional link, and the first time a DQPSK signal has been remodulated by a simple RSOA. The upstream bit rate of 1.25 Gbit/s was chosen due to the achievable modulation bit rate of commercially available devices. Upgrade of the upstream bit rate by replacement of the RSOA with a faster device would not affect the performance of the downstream signal. E.g. an amplified reflective electro-absorbtion modulator could be used. Such devices have been demonstrated at bit rates up to 10 Gbit/s in [5] and [6]. This makes the link proposed here very flexible in terms of upstream bit rate.

The use of phase modulation formats for the downstream transmission opens the possibility for ASK carrier remodulation with simple reflective SOA modulators at the customer premises since no amplitude modulation needs to be erased before ASK-remodulation and upstream transmission. Having an amplitude modulated incoming signal to the RSOA could also result in the upstream performance being dependent on the downstream bit pattern. This effect is avoided in the proposed scheme. In this way, the use of phase modulation of the downstream signal relaxes the requirements on the RSOA. Further, the high spectral efficiency of DQPSK relaxes the requirements of dispersion compensation, meaning that existing 10 Gbit/s binary modulated downstream channels can be upgraded to 20 Gbit/s without additional dispersion compensation. The use of distributed Raman amplification in the link and gain in the RSOA means that there is no need for discrete amplifiers along the transmission line, even though the long reach has been maintained.

2. Experimental setup

A schematic of the setup used in the experiments is shown in Fig. 1. The DQPSK transmitter is composed of a distributed feedback (DFB) laser emitting continuous wave (CW) light at 1551.3 nm, two Mach-Zehnder modulators (MZM) and a phase modulator (PM) (The modulators have been omitted in the figure for simplicity). The first MZM is driven by a 10 GHz clock, and carves the CW light into a pulse-train with a 10 GHz repetition rate. The other MZM and the PM provide the data modulation. They are both driven by a 2^7-1 bits long pseudo random bit sequence (PRBS). The MZM was driven between two transmission maxima, thereby giving a π phase shift, and the PM was driven to give a $\pi/2$ phase shift. Decorrelation was ensured by the difference in optical and electrical delay between the data modulators. The 2^7-1 word length was chosen for simplicity in the programming of the error detector. Moreover, because of the pattern independent power level of the RZ-DQPSK modulation format, no severe performance degradation would be expected from pattern effects.

The resulting 20 Gbit/s RZ-DQPSK signal was transmitted through 80 km of TrueWave®RS (TW RS) non zero dispersion shifted fiber. Its low dispersion of 4.6 ps/nm/km @ 1550 nm and high Raman gain efficiency of 0.71 1/W/km make it suitable for this type of system, and render dispersion compensation unnecessary for the specified setup and bit rate. The total dispersion of the link was 370 ps/nm. The link utilizes distributed Raman amplification, employing both co- and counter propagating pumping. Input power to the link was –2 dBm, and the output power of the link was –20.5 dBm with the pumps turned off and +0.9 dBm with the pumps turned on. Hence, the loss of the link was 18.5 dB, and the on-off gain of the Raman amplification was 21.4 dB. Employing a more conventional design based on standard single mode fiber (SSMF) would have reduced the efficiency of the distributed Raman amplification due to the lower Raman gain of SSMF. Additionally, dispersion compensation would have been necessary, e.g

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dispersion compensating fiber (DCF) with additional amplification to compensate for loss in the DCF. Overall, this would have added to the overall complexity of the system.

After downstream transmission, out of band spontaneous emission noise was filtered away using an optical bandpass filter with a 3 dB bandwidth of 1.3 nm. The 20 Gbit/s RZ-DQPSK signal was split by a 10 dB fiber coupler and the 90% output was detected by a SOA based pre-amplified receiver. This receiver design was chosen for its suitability for integration. The gain of the SOA was measured to be 10 dB. The phase modulation was converted to amplitude modulation by a fiber based one-symbol delay interferometer before direct detection by a pair of balanced photodiodes. A 20 Gbit/s RZ-DQPSK signal consists of two independent 10 Gbit/s tributaries. In a real system implementation, two receivers would be needed to detect both tributaries simultaneously. In the experiment they were measured one after the other. The error performance of the signal was analyzed by a programmable 10 Gbit/s error detector. Since no hardware precoding was utilized, the error detector was programmed with the expected DQPSK tributary.

Amplitude shift keying (ASK) at 1.25 Gbit/s was applied to the 10% output from the fiber coupler by a RSOA. This was driven by a 1.25 Gbit/s $2^7 - 1$ bits long PRBS non return to zero (NRZ) signal. The Optimized state of polarization into the RSOA was achieved with a polarization controller (PC). The $2^7 - 1$ PRBS was chosen as test pattern as it gives the closest match to the maximum run-length of a Gigabit Ethernet 8B/10B line code [8]. 1.25 Gbit/s ASK signal was then propagated upstream through the link. Average optical power into the RSOA was –15 dBm, at which power the RSOA provided 19 dB gain, resulting in an average upstream power into the link of –6 dBm. The extinction ratio of the ASK signal was 6 dB.

After upstream propagation, the ASK signal was led to a receiver via a circulator, out of band

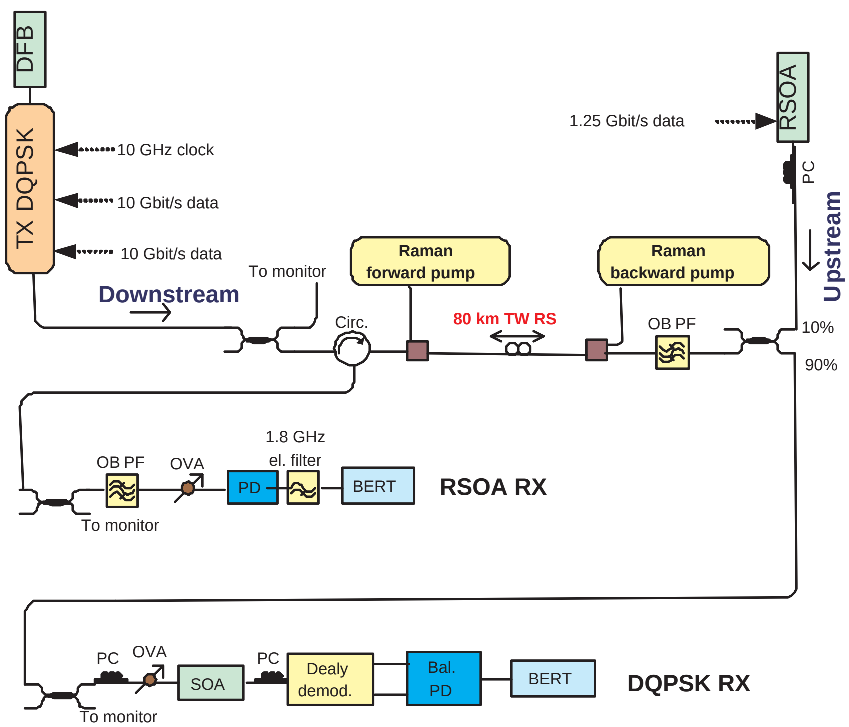

Fig. 1. Schematic of the setup used in the experiments.

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spontaneous emission noise was supressed by an optical band pass filter with a 3 dB bandwidth of 0.3 nm, and the signal was detected by a photodiode. After detection, the 10 GHz tone from the pulse carving was supressed using a 4th order low pass Bessel filter with a cut-off frequency of 1.8 GHz. Error performance is evaluated by a 1.25 Gbit/s error detector.

3. Results

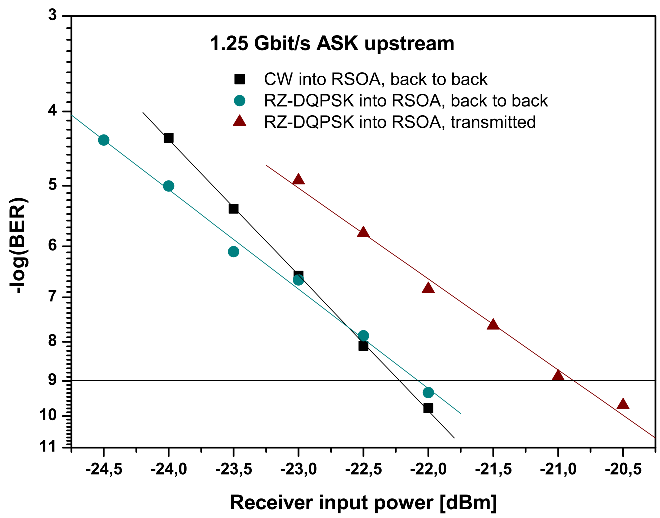

Fig. 2. BER of the 1.25 Gbit/s remodulated upstream signal.

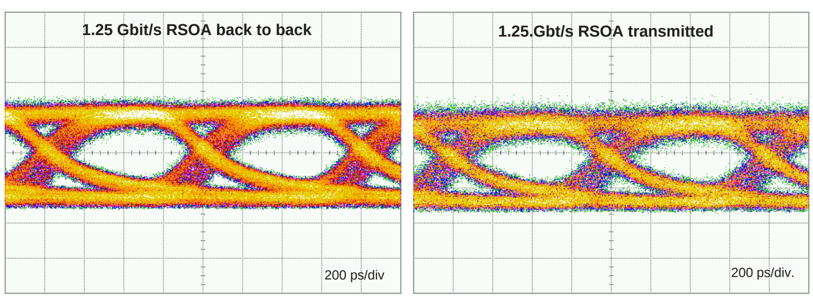

Fig. 3. Eye diagrams of the RSOA remodulated RZ-DQPSK signal before (left) and after (right) transmission.

The bit error ratio (BER) of the ASK signal was measured directly at the output of the RSOA (back to back) with CW light into the RSOA, as well as with the 10 Gbaud RZ-DQPSK signal into the RSOA in order to investigate the effect of the RZ-carving on the performance of the 1.25 Gbit/s ASK signal. The results are plotted in Fig. 2 along with the BER of the upstream transmitted ASK-remodulated RZ-DQPSK signal. Very little difference between the two back to back cases is observed. At a BER of 10^{-9}, the receiver sensitivity was –22.4 dBm for the CW, and –22.1 dBm for the RZ-DQPSK input. After transmission, the receiver sensitivity was –20.8 dBm, corresponding to a penalty of 1.3 dB. The low penalty is confirmed by the eye diagrams in Fig. 3, where only a slight degradation of the signal is observed.

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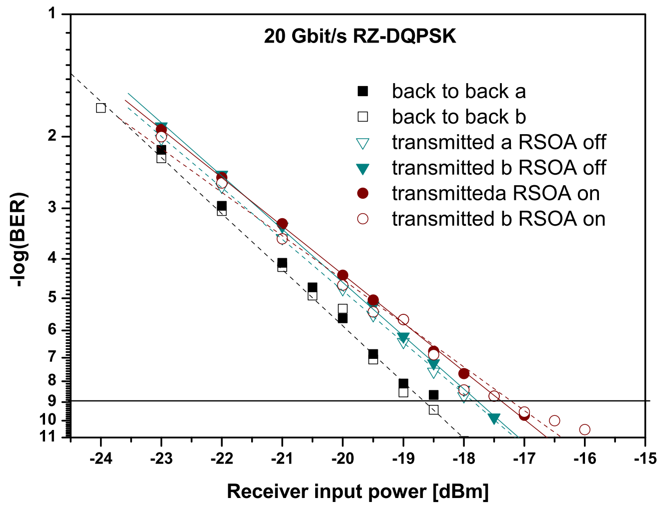

Fig. 4. BER of the 20 Gbit/s RZ-DQPSK downstream signal. a and b denote the two RZ-DQPSK tributaries.

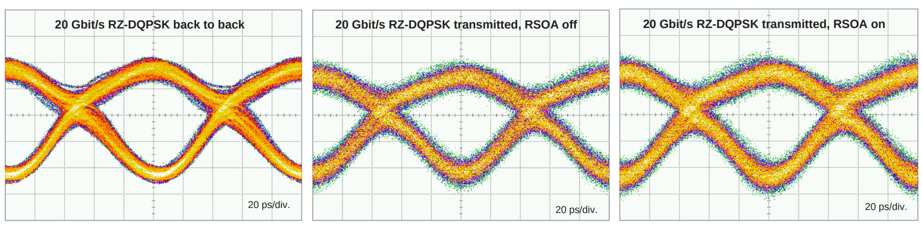

Fig. 5. Eye diagrams of the RZ-DQPSK signal back to back (left), after transmission without remodulation (middle), and after transmission with the remodulated upstream signal on (right).

Results of the BER measurements of the 20 Gbit/s RZ-DQPSK downstream signal are plotted in Fig. 4. Back to back performance was measured, as well as performance after transmission, both with the ASK-remodulated upstream signal on and with the RSOA disconnected. The back to back receiver sensitivity at a BER of 10^{-9} was –18.7 dBm and after transmission it was –17.7 dBm without the RSOA and –17.2 with the RSOA. No significant difference between the two DQPSK tributaries was observed. Eye diagrams of the 20 Gbit/s RZ-DQPSK signal is shown in Fig. 5. The good dispersion tolerance of the RZ-DQPSK modulation format is illustrated by the very limited pulse broadening after transmission. The pulse broadening undergone by a binary modulation format at 20 Gbit/s after 370 ps/nm total dispersion would have been considerably larger. For 20 Gbit/s NRZ on-off keying (OOK), the 1 dB eye closure limit is 250 ps/nm, corresponding to 55 km of NZ-DSF. Therefore, the long reach transmission could not have been achieved using 20 Gbit/s OOK without incorporating further dispersion compensation. [7]. Also, the very similar performance with- and without the counterpropagating ASK modulated signal is confirmed.

In order to estimate the end user capacity of the proposed system, a crude power budget calculation can be performed. Taking into account the loss of two arrayed waveguide gratings (AWGs), and assuming said loss to be 4 dB each, the power margin is approximately 19 dB for the downstream signal and 16 dB for the upstream signal. These power margins can be

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used fr dimensioning the system, for example assuming a maximum distance of 20 km from the passive splitting point to the end user, and 0.2 dB/km propagation loss, 25 end users can be reached within the margin of the upstream signal. For the downstream signal, this leaves an additional 3 dB margin, allowing for further simplification of the system by single ended detection of the DQPSK signal.

4. Conclusion

A bidirectional Raman amplified 80 km long reach PON-link has been demonstrated. A 20 Gbit/s RZ-DQPSK modulated carrier was transmitted downstream and detected error-free, ASK-remodulated at 1.25 Gbit/s with an RSOA and transmitted upstream through the same fiber. The RZ-DQPSK receiver sensitivity at a BER of 10^{-9} was –17.2 dBm with the upstream signal on. The receiver sensitivity of the upstream signal was –20.8 dBm. The ASK-remodulated upstream signal induced no measurable BER degradation of the downstream RZ-DQPSK signal.

The presented bidirectional link, employing a single fiber with distributed Raman amplification and carrier remodulation at the customer premises, offers advantageous features for applications in long reach PONs, such as reduced complexity in the fiber link, downstream bit rates up to 20 Gbit/s, and easy upgradability of the upstream bit-rate.

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