OSA/OFC/NFOEC 2011

OWL1.pdf

320 Gbps DPSK transmitter and self-tracked receiver based on four-wave mixing

A.O.J. Wiberg[1], C.-S. Brès, B.P.-P. Kuo, E. Myslivets, N. Alic, and S. Radic

Department of Electrical and Computer Engineering, University of California San Diego, 9500 Gilman Drive, La Jolla, CA 92093-0407, [1]e-mail: awiberg@ucsd.edu

Abstract: A novel RZ differential phase-shift keyed transmitter and self-tracked receiver based on cavity-less pulse generation and four-wave mixing for data rate of 320 Gb/s. The performance was quantified with error-free operation at an OSNR of 31.2dB.

OCIS codes: (230.2285) Fiber devices and optical amplifiers; (190.4380) Nonlinear optics, four-wave mixing; (060.2330) Fiber optics communications.

1. Introduction

All recent data traffic surveys imply a continued growth in the capacity demand. In order to address the capacity shortage in optical networks that is beginning to unravel, coherent and high-spectral efficient channels have been introduced and have gained considerable attention recently. On the other hand, network management dictates that the granularity of channels be increased, with 100 Gb/s/channel plans to be deployed shortly. Consequently, channel plans relying on Tb/s granularity are not only realistic but are fully expected to be deployed in the next decade.

Very high bit rate channels can be generated employing spectrally efficient modulation in both amplitude and phase, in conjunction with return-to-zero (RZ) format for optical time division (OTD) multiplexing. Consequently, transmitters and receivers capable of multiplexing/demultiplexing signal tributaries are the key subsystem for realization of format transparent ultra-fast OTD mutliplexed systems. While multiple platforms have been examined [1], fiber optic parametric amplifiers (FOPA) present many advantages, and are considered the superior candidates for optical processing beyond 100 Gb/s. Recently, phase-preserving optical processing (a critical functionality for modulation format transparency) of high data speed wave forms employing four-wave mixing (FWM) has been demonstrated [2]. Moreover, the parametric processing has been demonstrated to possess wide bandwidth and high processing speed [3], its phase preserving prosperities establishes it as an attractive platform for real-time high speed signal processing.

In this work, we present a novel differential return-to-zero phase-shift keyed (DPSK) transmitter and a phase preserving self-tracked receiver. Pulse generation is based on a cavity-less approach for both transmitter and the sampling receiver [4], which was shown to be a reliable alternative to mode-locked laser pulse sources. We show generation of the highest baud rate phase modulated data based on a cavity-less pulse source, that relies on the phase preserving property of the FWM to compress and produce short pulses with simultaneous built-in phase modulation. Furthermore, we expand the FWM based self-tracking sampling receiver [5] and show for the first time its exceptional operation in conjunction with DPSK signals with all eight 40 Gb/s DPSK modulated tributaries extracted from the 320 Gb/s. The excellent performance of the transmitter and sampling receiver was quantified with error-free operation (BER=10^{-9}) for an optical signal to noise ratio (OSNR) of 31.2 dB.

2. Experiment

The experimental setup is depicted in Fig. 1 and consists of two blocks, the 320 Gb/s DPSK-transmitter, and the 320 Gb/s OTD DPSK-demux/receiver. The transmitter is based on a cavity-less pulse source [4], with built-in data phase modulation, which is based on three stages of pulse compression. In the first stage, 40 GHz pulses are formed from a CW laser at 1575 nm with a cavity-less pulse source [4]. In the two subsequent non-linear stages based on self-phase modulation and filtering and fiber-optic parametric amplifier (FOPA), respectively, the pulses are further compressed to 1.2 ps [6]. In the latter stage the phase preserving properties of FWM are taken advantage of in order to impart the phase information on the created idler pulses by modulating the CW seed with DPSK data. By

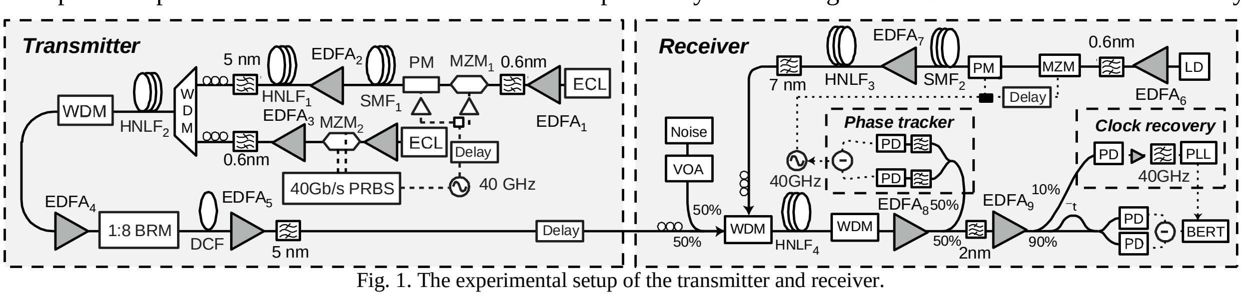

Fig. 1. The experimental setup of the transmitter and receiver.

sampling out the NRZ-DPSK, a retiming of the data is also performed. The scheme is not restricted to phase only modulation, but is also fully applicable to amplitude, or quadrature amplitude modulation (QAM). The introduced scheme is conceptually different from the previously realized pulse source in [6], whereas short pulses are first generated and subsequently modulated. As demonstrated in Fig. 1, the CW signal seed positioned at 1609 nm was modulated with 40 Gb/s DPSK signal using a push-pull MZM_2. The DPSK modulated signal seed was combined with the pulsed pump, resulting in a creation of high quality idler pulses carrying RZ-DPSK 40 Gb/s data stream centered at 1542 nm. It is important to note that the FOPA stage has many functionalities contributing to the generation of high quality data: pulse compression, improvement of pulse extinction ratio, and data retiming. The RZ-DPSK data stream is subsequently OTD multiplex in a three stage bit-rate multiplier (BRM) to a 320 Gb/s RZ data-stream and filtered by a 5 nm optical band pass filter (OBPF).

The 320 Gb/s receiver is based on a sub-rate picosecond parametric sampling gate, as shown in Fig. 1. The sampling gate is based on the parametric interaction between strong 40 GHz pump pulses and the 320 Gb/s signal, generating an idler pulse (i.e. a sample) temporally coinciding with the pump pulse presence. A particular TDM 40 Gb/s tributary (i.e. one of the eight tributaries of the 320 Gb/s input) is selected by pump-signal temporal synchronization. The sub-rate sampling pulse source is based on an RF-driven cavity less pulse source [4], similar to the data pulse source. The FWM sampling gate was realized in a 25 m segment of $HNLF_4$, characterized by a ZDW of 1572.8 nm and subrate (idler) samples were formed at 1602 nm containing a 40 Gb/s DPSK tributary data stream. The 40 Gb/s signal was filtered out with a WDM and a fraction of the 40 Gb/s idler data output power was tapped off and sent to a phase tracker (see Fig. 1.), which locked the phase between data and sampling pulses driven by an *independent* microwave synthesizer. The phase tracker relies on the asymmetric cross-phase modulation (CPM) -induced spectral broadening of the signal and idler, which allows an un-ambiguous timing information retrieval [5], and is demonstrated for the first time for a phase modulated signal in this work. The system was fully characterized by a rigorous bit-error rate (BER) measurements, including the clock recovery. The BER was measured as a function of the optical signal to noise ratio (OSNR), where optical noise (amplified spontaneous emission: ASE) was added to the incoming signal at the input of the sampling gate. The noise power level was controlled by a VOA, allowing strict OSNR limited system performance characterization. Furthermore, a programmable optical delay was used in the incoming signal path to enable temporal alignement of the sampling gate between the 8 different 40 Gb/s tributaries in the 320 Gb/s data stream, thus allowing the full system performance characterization,.

3. Results

The 40 GHz pulses generated with the cavity-less source with subsequent non-linear compression are shown in Fig. 2*(a)*. The pulses have a high SNR of 40 dB and a temporal duration of 1.4 ps. The pulses' quality is significantly improved by the second FOPA stage, in which, additionally, the phase information was simultaneously being imparted onto the information bearing pulses. The spectrum of the FOPA compression/modulation stage is displayed in Fig. 2*(c)*, before and after bandpass filtering with a 5 nm filter. The DPSK modulated pulses centered at 1542 nm are shown in Fig. 2*(b)* after a delay interferometer. It is evident from Fig. *2(b)* that the pulses are compressed compared to the pump pulses, and that pulse shape is improved given the suppression of pedestals. The temporal width of the DPSK modulated pulses was 1.2 ps. The final output of the transmitter was a threefold bit-rate multiplied DPSK modulated pulses with an aggregate data rate of 320 Gb/s. The eye-diagram after the delay interferometer in Fig. 3*(b)* shows the exceptional signal quality having a Q of 20.3 dB, in concurrence with the the quality of the modulated pulses, and the significant suppression of pedestals.

The 320 Gb/s self-tracked receiver based on the parametric sampling gate was driven with sub-rate 40 GHz pulses, shown in Fig. 3*(a)*. The signal is combined (and temporally precisely aligned) with the sampling stream in $HNLF_2$ producing an idler at 1608 nm, as shown in Fig. *3(c)*. The pulse tracking enabled a stationary detection of one of the 40 Gb/s tributaries at a time. A representative eye-diagram after the delay interferometer of a 40 Gb/s

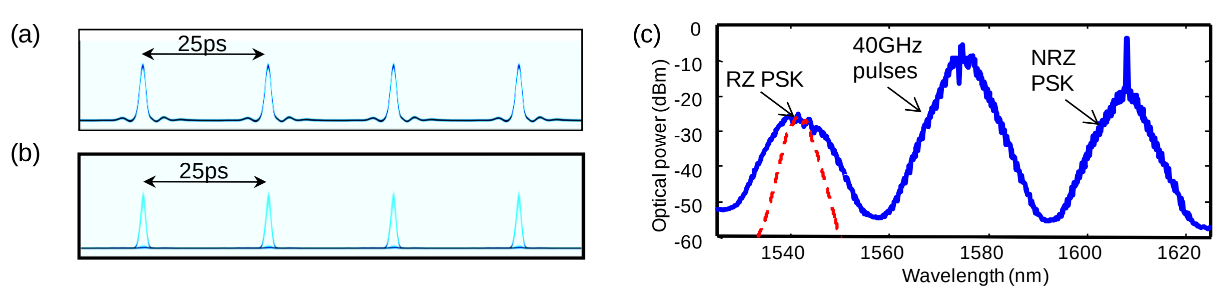

Fig. 2. (a) 40GHz pulse source for data generation. (b) 40Gbps PSK after wavelength and format conversion, and delay interferometer. (c) Optical spectrum of the wavelength and format conversion (solid line) and signal after 5nm OBPF.

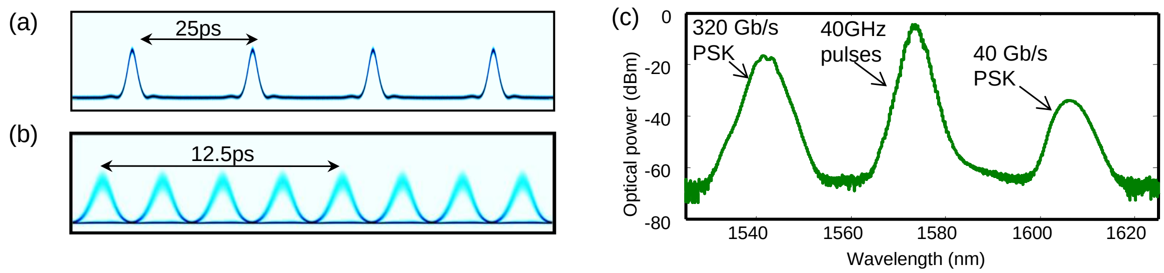

Fig. 3. (a) 40 GHz pulse source for sampling. (b) 320Gb/s PSK. (c) Optical spectra of parametric sampling operation

tributary is shown as an inset in Fig. 4, demonstrating both phase tracking stability, as well as phase preservation of the parametric process.

In order to verify the full system operation of the transmitter and receiver, a rigorous bit error ratio (BER) measurements of all 8 tributaries in the aggregate high data rate channel were measured with respect to the OSNR, as explained in the previous section. The optical delay of the 320 Gb/s data stream was used to switch between the tributaries. The results are presented in Fig. 4. as BER versus OSNR, where the noise power was measured with 0.1 nm reference resolution bandwidth. The BER measurements of all 8 tributaries are showing error-free performance. The average BER of the 320 Gb/s channel is highlighted and the sensitivity, defined as OSNR to reach BER of 10^{-9}, was at an OSNR of 31.2 dB. This is to be compared with the back-to-back (i.e. a non-bit-rate multiplied) 40 Gb/s signal having a sensitivity of 29.7 dB OSNR, measured bypassing the sampling gate. Result displayed in Fig. 4 does take into account the 9 dB average power difference between the original (i.e. 40 Gb/s) and the BRM 320 Gb/s streams. The penalty of 1.5 dB, observed in Fig. 4 is in part attributed to the non ideal driving conditions of the Mach-Zehnder modulator used as well as to the performance of the BRM.

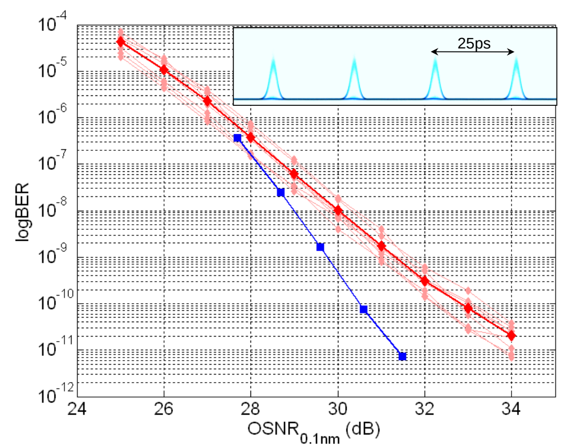

Fig. 4: BER measurements of all 8 tributaries of the 320 Gb/s PSK compared to 40 Gb/s back to back. Inset: eye of sampled 320 Gb/s PSK

4. Conclusion

We have proposed and experimentally demonstrated a novel RZ-DPSK transmitter and self-tracked receiver for high speed OTD multiplexed channel based on the cavity-less pulse generation and FWM. The self-tracked FWM based receiver was for the first time demonstrated with a phase-modulated input signal with fully independent 320 Gb/s transmitter and receiver The performance was quantified by rigorous BER measurements with respect to the OSNR of *all* tributaries with phase tracking and clock recovery. Error free operation was demonstrated for all eight 40 Gb/s tributaries with the average OSNR sensitivity of 31.2 dB, fully validating that cavity-less short pulse generation and parametric sampling for processing of DPSK signals. Due to the inherent phase preserving sampling gate this architecture is equally applicable to intensity, phase or QAM modulations.

5. Acknowledgement

This material is based in part on research sponsored by Air Force Research Laboratory (AFRL) and the Defense Advanced Research Agency (DARPA) under agreement number FA8650-08-1-7819 Parametric Optical Processes and Systems. The authors gratefully acknowledge Sumitomo Electric Industries for providing the highly non-linear fiber used in the experiment.

6. References

[1] L.K. Oxenløwe, M. Galili, H.C. Hansen Mulvad, H. Hu, H. Ji, J. Xu, E. Palushani, J.L. Areal, A.T. Clausen and P. Jeppesen, ECOC 2010, 19-23 September, 2010, Torino, Italy, Mo.1.A.1.
[2] M. Westlund, M. Sköld and P. A. Andrekson, Optical Fiber Communication Conference (OFC 2008), PDP12, San Diego, CA, USA.
[3] E. Myslivets, B. P.-P. Kuo, A. O. J. Wiberg, S. Zlatanovic, S. Moro, F. Gholami, A. Peric, C.-S. Brès, N. Alic, and S. Radic, Optical Fiber Communication Conference (OFC), Post deadline paper PA4, San Diego, CA, USA 2010.
[4] A.O.J. Wiberg, C.-S. Bres, B.P.-P. Kuo, E. Myslivets and S. Radic, ECOC 2009, Vienna, Austria, Paper 5.2.3, 2009.
[5] B.P.-P. Kuo, A.O.J. Wiberg, C.-S. Brès, and S. Radic, ECOC 2010, 19-23 September, Turin, Italy, Paper Th.10.C.3, 2010.
[6] A.O.J. Wiberg, B.P.-P. Kuo, C.-S. Brès, and S. Radic, ECOC 2010, 19-23 September, Turin, Italy, Paper Th.9.C.1, 2010.