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32-krad/s Polarization and 3-dB PDL Tracking in a Realtime Digital Coherent Polarization-Multiplexed QPSK Receiver

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***Abstract* — The tolerance against fast polarization changes and PDL of a digital coherent QPSK receiver is determined in a 2.8 Gb/s realtime polarization-multiplexed transmission experiment. The sensitivity penalty for polarization changes with a speed of 32 krad/s on the Poincaré sphere is 0.5 dB.**

***Index Terms* — Optical communication, quadrature phase shift keying, polarization multiplexing, synchronous detection.**

I. Introduction

Polarization multiplexing is an efficient way to double the capacity of optical transmission systems. But fast polarization state and polarization-dependent loss (PDL) changes that occur in the fiber link can severely degrade the receiver sensitivity [1]. There are two approaches to compensate for these distortions at the receiver: One is an optical polarization controller, which can be used with all kinds of receivers [2]. The second possibility is to realize electronic polarization control inside a coherent receiver [3]. This approach has already extensively been studied, mostly in combination with quadrature phase shift keying (QPSK) modulation [4]. But until recently [5], the control speed of the polarization controller has not been an issue.

In this paper we investigate the tolerance against fast polarization changes and PDL of an improved version of the realtime polarization-multiplexed QPSK receiver published in [5] at a data rate of 2.8 Gb/s. The control time constant as well as the loop delay are reduced while the control accuracy is preserved, allowing now to tolerate 32 krad/s polarization changes with a 0.5 dB sensitivity penalty.

II. Experimental Setup

A DFB laser (Δf_S = 1 MHz) signal is modulated at 4x700 Gb/s by a precoded 2^{31}-1 PRBS (decorrelation of I&Q by 64 bit, decorrelation of polarizations by 7 bit), utilizing two QPSK modulators to transport in-phase and quadrature data in two orthogonal polarizations at a total data rate of 2.8 Gb/s (Fig. 1). After transmission over 80 km of fiber, the signal is fed into a polarization scrambler which consists of 4 quarter-wave plates, one half-wave plate (HWP) and an optional PDL element. The 4 quarter-wave plates run at incommensurate rates between –6 and +6 Hz and ensure that the polarization state rotates with all possible radii and reaches all possible points on the Poincaré sphere. The HWP is driven by a motor, whose speed can be adjusted from 0 to 500 Hz. With a rotation speed transformation of 39/15 from the motor to the HWP and 8π rad polarization change on the Poincaré sphere per HWP rotation the maximum speed of polarization changes is >32 krad/s.

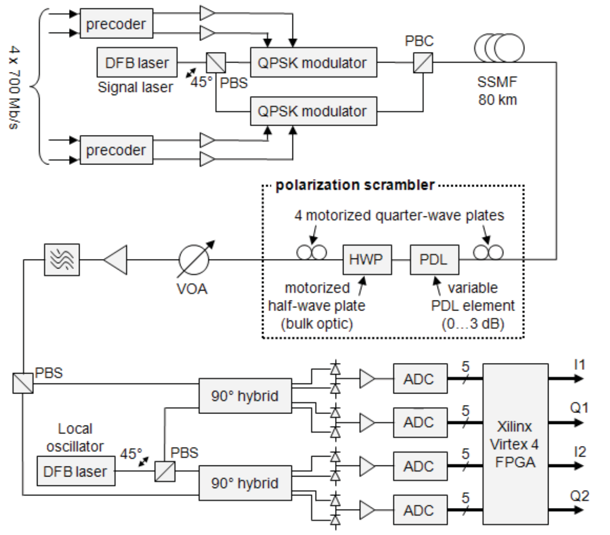

Fig. 1 Setup for 2.8 Gb/s realtime synchronous optical QPSK transmission with polarization division multiplex.

The receiver input power is controlled by a variable optical attenuator (VOA). The polarization diversity coherent optical receiver consists of two integrated-optical 90° hybrids, in which the received signal is superimposed with the local oscillator signal (Δf_{LO} = 1 MHz). After optical-to-electrical and analog-to-digital conversions, a purely electronic manipulation of the electronic equivalent of the optical field vector is undertaken in a field-programmable gate array (FPGA). A feedforward scheme recovers the optical carrier, and the inphase and quadrature data streams of both polarizations are demodulated synchronously. Finally the recovered bit streams are fed into a bit error rate tester to determine the BER.

Correlation of data before and behind the decision circuits is used to update the elements of the matrix which transforms the received electronic field vector, composed of two mixed polarizations, into a polarization-separated vector [3]. The control gain of the integral controller is switchable between 2^{-8} and 2^{-10}, which allows to switch the control time constant *c* between 0.75 µs and 3.0 µs.

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III. MEASUREMENT RESULTS

Initially the HWP motor is halted and the PDL is set to 0 dB to measure the reference sensitivity of the coherent receiver for the two values of the polarization control time constant *c*. As shown in Fig. 2 at a BER of 10^{-3} the slower polarization control with $c = 3.0\ \mu s$ outperforms the system with $c = 0.75\ \mu s$ by 0.15 dB in terms of receiver sensitivity. This can be explained by the fact that the slower control achieves a higher accuracy. As in previous measurements a BER floor at around $2 \cdot 10^{-7}$ is detected for receiver input powers above −35 dBm, which is caused by the high ratio 0.0029 of sum linewidth times divided by symbol rate [5].

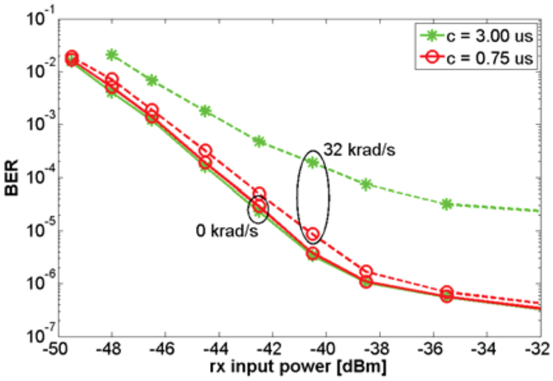

Fig. 2 Measured BER (I&Q averaged) vs. optical power at the preamplifier input for different speeds of polarization change.

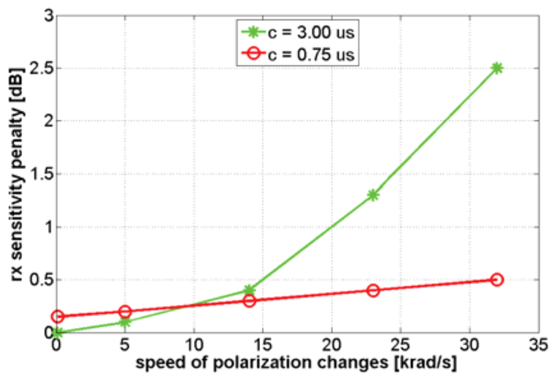

Fig. 3 Receiver sensitivity penalty vs. speed of polarization changes on the Poincaré sphere.

In a second step the polarization scrambler is switched on to generate polarization changes with up to 32 krad/s on the Poincaré sphere, and the tolerance of the receiver against these fast polarization changes is determined (Fig. 3). Assuming that a sensitivity penalty of 0.5 dB is tolerable, the receiver with $c = 3.0\ \mu s$ can compensate for polarization changes with a speed of 15 krad/s. The receiver with $c = 0.75\ \mu s$ can even tolerate polarization changes with a speed up to 32 krad/s on the Poincaré sphere. Note that the HWP also features a position-dependent loss of about 2 dB.

Finally the variable PDL is set to 3 dB and its added influence on the system performance is analyzed. For these measurements only the receiver with $c = 0.75\ \mu s$ was investigated. The 3 dB PDL always adds an additional sensitivity penalty of 0.7 dB (Fig. 4). In this context it is irrelevant whether the polarization scrambler is halted or not.

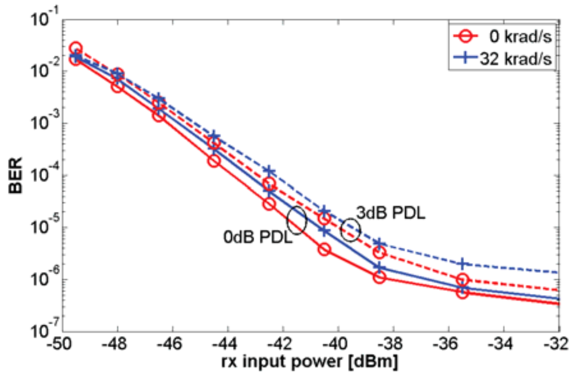

Fig. 4 BER vs. optical power at the preamplifier input, with and without additional 3 dB PDL (c = 0.75 µs).

IV. SUMMARY

We have demonstrated realtime electronic tracking of optical polarization changes and PDL in a realtime polarization-multiplexed synchronous optical QPSK transmission system at a data rate of 2.8 Gbit/s. With severe endless polarization changes at a speed of 32 krad/s, the sensitivity penalty of the receiver is 0.5 dB. The sensitivity penalty introduced by a PDL element of 3 dB is 0.7 dB and independent of the polarization scrambling speed.

ACKNOWLEDGEMENT

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