Fully-Integrated Polarization-Diversity Coherent Receiver Module for 100G DP-QPSK

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Abstract: A new compact coherent receiver module comprising a micro-optic polarization beam splitter and two InP-based 90^0 hybrids with integrated photodiodes is characterized at 112 Gbit/s DP-QPSK. A penalty of only 1.3 dB in OSNR sensitivity at a BER of 10^{-3} compared to theory was obtained at C-band wavelengths.

OCIS codes: (060.1660) Coherent Communication; (250.3140) Integrated optoelectronic circuits

1. Introduction

The polarization diverse dual-quadrature coherent receiver is a key component in 100G DP-QPSK long-haul fiber optic links. In its typical configuration it consists of two polarization beam splitters, two optical 90° hybrids, eight photodiodes (PDs) and two transimpedance amplifiers. Because of this complexity, a fully-integrated coherent receiver in one package is highly desirable. It saves footprint, packaging cost and reduces the number of fiber-based inter-component connections and thus allows for a better control of skew. Different degrees of receiver integration have been published recently including a coherent detector module based on InP-monolithic integration [1], a monolithic polarization-diversity coherent receiver photonic integrated circuit (PIC) on Si [2], a monolithic InP multi-wavelength polarization-diversity coherent receiver PIC [3], a dual-polarization coherent receiver module [4], and a polarization-diversity coherent receiver module with silica-based hybrid integration [5].

In this paper we report on a new compact 100G polarization-diversity coherent receiver module based on hybrid integration of a free-space micro-optic polarization beam splitter (PBS) with InP PICs. The fully packaged receiver is successfully operated in a back-to-back experiment with 112 Gbit/s non-return-zero (NRZ) dual-polarization quadrature phase shift keying (DP-QPSK) signals at 1530 nm, 1550 nm and 1563 nm wavelength.

2. Polarization-diversity coherent receiver module

The main building blocks of the receiver are shown in fig. 1. The micro-optic assembly is symmetric for both signal (SIG) and local oscillator (LO) paths and consists of a collimator (C), two half wave plates (HWP), the PBS cube, a skew compensator (SC) and two micro-lens arrays (L). Whereas the SIG input polarization is arbitrary, the linearly polarized LO light is launched through the slow axis of the polarization maintaining input fiber (PMF). For convenience the first HWP is used to ensure 3 dB LO splitting ratio. However, it should be noted that the HWP can be omitted in future assemblies once the PMF slow axis is aligned correctly with regard to the PBS. To achieve highest symmetry in both channels, X and Y, a second HWP is integrated in the X channel to perform a TM-to-TE

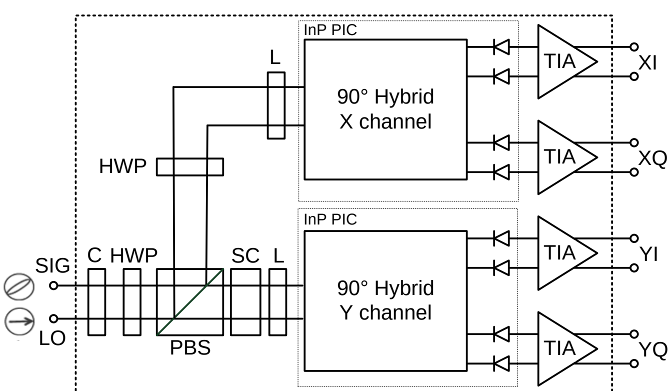

Fig. 1. Coherent receiver architecture.

Fig. 2. Coherent receiver module. The second fiber pipe is not used and will be removed in a future package re-design.

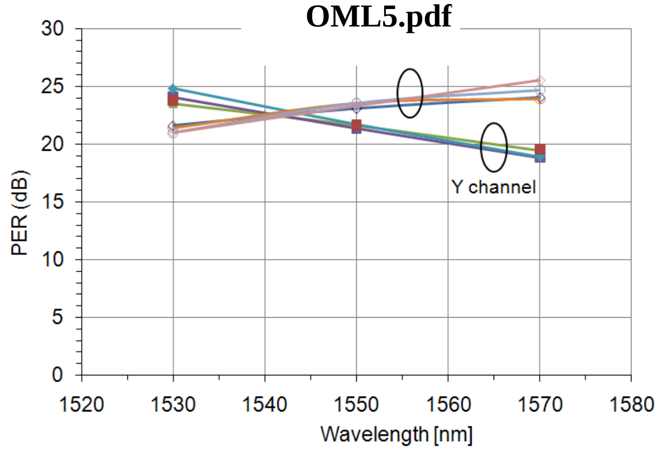

Fig. 3. PER vs. wavelength in signal path.

conversion. In return and to minimize the channel path length difference a skew compensator (SC) is integrated in the Y channel. Due to mechanical tolerances we estimated a channel skew of less than 5 ps. The four beams are finally coupled through micro-lens arrays into the integrated optical spot size converters of the InP-based PICs. Each of the two PICs comprises a 2x4 multi-mode interference (MMI) coupler 90° hybrid together with four waveguide pin photodiodes [1]. Four linear differential transimpedance amplifiers (TIAs) are co-packed in the module [4]. The package with a body size of 27 mm x 40 mm x 6 mm has a coplanar waveguide rf-interface for surface mount assembly of the device (fig.2). The 3 dB bandwidth of the receiver module was 26 GHz as previously reported in [4].

We measured an average responsivity over all photodiodes of 0.03 A/W at 1550 nm including the 9 dB intrinsic loss of the PBS and the 2x4 MMI coupler. Fig. 3 shows the polarization extinction ratio (PER) measured for all eight photodiodes versus wavelength using the signal input. A PER of >19 dB was obtained for all PDs. A similar result within 0.4 dB was obtained when using the LO input.

3. DP-QPSK measurement results

The experimental setup for the back-to-back characterization of the coherent receiver module in a DP-QPSK system is shown in fig 4. At the transmitter, an external cavity laser (ECL) followed by a single-drive IQ modulator (Fujitsu) is used as signal source. The IQ-modulator is driven by the in-phase and quadrature component of a 28 GBd QPSK signal. The bit sequence consists of 2^{14} randomly chosen bits, which are generated by a field-programmable gate array (FPGA) -based real-time transmitter (Tx). After modulation the single polarization signal passes a polarization multiplexing stage (PMUX), consisting of a coupler, a delay line and a polarization beam combiner. On the receive side, a variable optical attenuator (VOA) and an erbium doped fiber amplifier (EDFA) allow for varying the optical signal-to-noise ratio (OSNR). After passing the preamplifier and a 10 dB coupler for OSNR evaluation the signal is filtered and boosted by a second EDFA. The average optical signal power launched into the coherent receiver was -5.5 dBm. The light of a second free-running ECL with about 100 kHz linewidth was used as LO. After amplification and filtering the average optical LO power launched into the coherent receiver was 14.5 dBm. While the state of polarization of the signal light was arbitrary during the experiments, the LO light was launched into the slow axis of the receiver's polarization maintaining input fiber. For the experiment the receiver module was mounted on an adapter board with coaxial rf-interface. Both, photodiodes and TIAs were operated at 3.5 V. A Tektronix 50 GSa/s real-time oscilloscope with 4 channels and 8 bit nominal resolution was used as analog-to-digital converter (ADC) to capture and digitize the output voltages of the coherent receiver (XI, XQ and YI, YQ). The digital post-processing was performed offline in a computer. The post-processing includes: resampling to an integer number of samples per symbol, correction of the 90° hybrid phase errors and imbalance by using the Gram-Schmidt orthogonalization [6], intra-scope skew correction and FFT based LO offset frequency correction [7]. After that, the two polarization tributaries are separated and the signal clock is recovered by four FIR filters arranged in a butterfly structure. The corresponding filter coefficients are adapted using the constant modulus algorithm

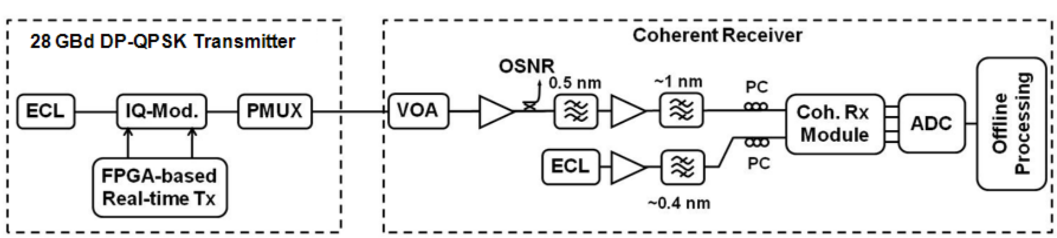

Fig. 4. Experimental setup for back-to-back measurements.

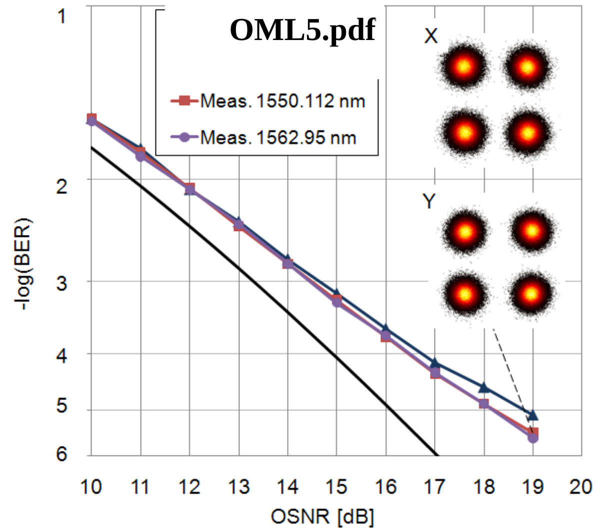

Fig. 5. BER vs. OSNR (0.1 nm optical bandwidth) at 112 Gbit/s. The insets show the constellation diagrams of X and Y channels at OSNR = 19 dB.

(CMA). After pre-convergence the error criterion is switched to the multi-modulus algorithm (MMA) described in [8] and finally the equalizer is switched to decision directed mode. After equalization, the bits of the individual tributaries are decoded and errors are counted. Measurements with 112 Gbit/s DP-QPSK modulation format were carried out at signal wavelengths of 1530 nm, 1550 nm and 1563 nm. It should be noted that the LO wavelength was adjusted to the particular signal wavelength to maintain a small frequency difference between signal and LO of a few MHz. Fig. 5 shows the measured bit-error ratio (BER) vs. OSNR together with a theoretical curve obtained from [9]. For a BER of 10^{-3} an OSNR of 14.6 dB was required at all considered wavelengths. Compared to theory, this is a penalty of only 1.3 dB. At BER 10^{-5} the required OSNR was 18.2 dB at 1550 nm and 1563 nm. However, at 1530 nm wavelength we observed an additional penalty of 0.6 dB at BER 10^{-5} which can be attributed partly to imperfections in the transmitter, filters and in the receiver.

4. Summary

The to-date smallest polarization-diversity coherent receiver module for 100G is presented. The receiver is based on the hybrid integration of free-space micro-optics and InP PICs. It has a high polarization extinction ratio of >19 dB over the C-band. The receiver was successfully tested in back-to-back system experiments at 112 Gbit/s DP-QPSK. Compared to theory, we found a penalty of only 1.3 dB in OSNR sensitivity at BER 10^{-3} for three considered C-band wavelengths.

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