European "synQPSK" Project: Toward Synchronous Optical Quadrature Phase Shift Keying with DFB Lasers

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Abstract: Key components for a synchronous 10-Gbaud, 40-Gbit/s QPSK polarization division multiplex transmission testbed are being developed: $LiNbO_3$ Z-cut QPSK modulator, $LiNbO_3$ 90° hybrid co-packaged with balanced photoreceiver OEICs, SiGe/CMOS circuits for digital signal processing.

OCIS codes: (060.1660) Coherent communications; (060.2920) Homodyning

1. Introduction

Synchronous quadrature phase shift keying (QPSK) transmission combined with polarization division multiplex is an extremely attractive modulation format for metropolitan area and long haul fiber communication [1–7]. All linear optical distortions (polarization transformations [8, 6], polarization mode and chromatic dispersions) can in principle be equalized without losses in the electrical domain. Dispersion tolerance is also good due to the lowered symbol rate. Distinct advantages exist also over all other modulation formats, including duobinary, DPSK and DQPSK. The European Commission funds in its FP6 under contract 004631 research on "Key components for synchronous optical quadrature phase shift keying transmission". This "synQPSK" project (http://ont.upb.de/synQPSK) aims to realize all components which are not readily found on the market: $LiNbO_3$ QPSK modulators in the transmitter, $LiNbO_3$ optical 90° hybrids, InP balanced photoreceivers – reliably co-packaged with the 90° hybrids – and SiGe/CMOS integrated electronic circuits for signal conditioning in the receiver. Standard DFB lasers are expected to be tolerable for signal and local oscillator lasers due to a carrier recovery concept that requires no phase-locked loop. It shall be implemented in the receiver by analog-to-digital conversion and subsequent CMOS signal processing. The targeted symbol rate is 10 Gbaud which amounts to 40 Gbit/s, plus FEC overhead. All components and contributions shall be validated in a testbed (Fig. 1). The key components to be developed are shaded.

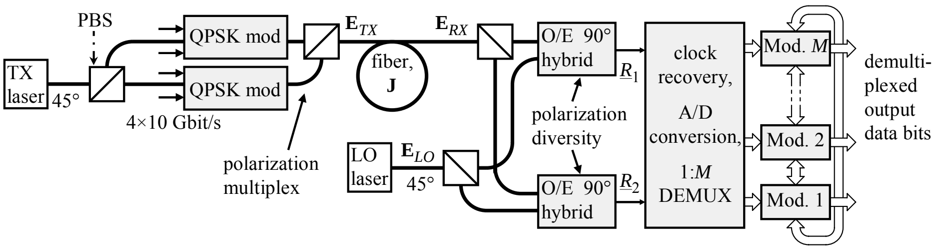

Fig. 1. Planned synchronous QPSK polarization division multiplex transmission testbed, with shaded key components.

2. Low-loss, low-voltage, zero-chirp QPSK modulators in poled Z-cut $LiNbO_3$

QPSK modulation can be generated in two optical Mach-Zehnder modulators, one for each quadrature. Photline in France will develop such modulators, integrated together on one $LiNbO_3$ chip in a Mach-Zehnder superstructure as shown in Fig. 2 left for one polarization. $LiNbO_3$ stands for lowest insertion loss and cost compared to other materials. Z-cut Mach-Zehnder modulators feature the lowest possible driving voltages, lower than for the X-cut. This is important to keep power dissipation and cost of modulator drivers at a minimum. A proprietary technique, the domain inversion in the Z− zone, will enable Photline to fabricate them with the required vanishing chirp. Here the crystal is submitted to a ferroelectric domain inversion localized on approximately half of the active length, and the accumulated chirp in both halves cancels [7]. Constant (or slowly adaptive) bias voltages (DC1 ... DC3) assure that the modulation diagram is stable.

Z-cut modulators have been fabricated with bandwidth-optimized electrodes and package. Fiber-to-fiber insertion loss is 6.5dB and ASK driving voltage is 6 V. The RF bandwidth is >25 GHz. Good performance is obtained for 10 Gbaud ASK (2.2 ps RMS jitter, 25 ps rise time) and (D)QPSK modulation as well as its interferometric demodulation (Fig. 2 right). In the future some modulator bandwidth can be traded against a lower drive voltage.

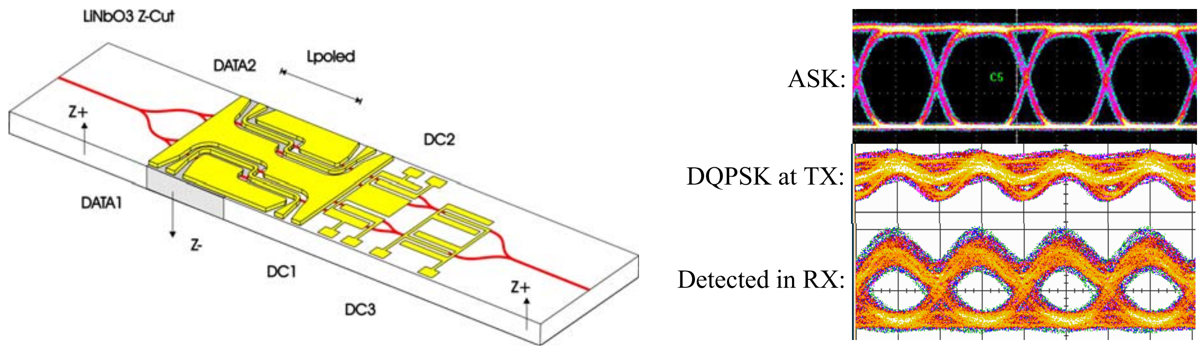

Fig. 2. QPSK modulator with two Mach-Zehnder modulators placed inside an interferometer superstructure (left). The domain inversion in the Z− zone assures near-zero chirp behavior with the lowest possible driving voltages. Exemplary 10 Gbaud eye diagrams (right) show ASK and (D)QPSK suitability. (D)QPSK eye diagrams were detected with a 12 GHz bandwidth.

3. Receiver front end consisting of co-packaged $LiNbO_3$ 90° hybrid and integrated photoreceivers

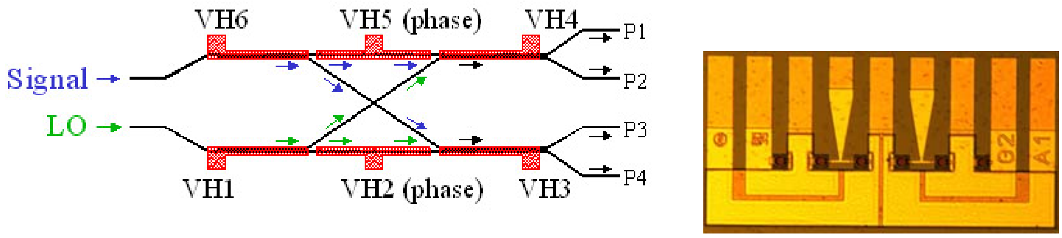

Fig. 3. Sketch of a 90° hybrid in $LiNbO_3$ (left) and fabricated PIN photodiode array including alignment diodes (right).

Heterodyne receivers are too difficult to implement at high data rates since the intermediate frequency must be a multiple of the clock frequency. Received and local oscillator (LO) signals are therefore, after initial splitting which is controlled by voltages VH1, VH6, respectively, superimposed twice (at VH3, VH4), once in phase and once in quadrature, and the relative phase is adjusted by VH2, VH5 (Fig. 3 left). Such 90° hybrids [10] are being developed by CeLight Israel Ltd.. The signals are to be differentially detected and amplified in PIN-TIA OEICs which are being developed by the Univ. Duisburg-Essen. As a preliminary step, IPAG in Duisburg has fabricated PIN diode arrays (Fig. 3 right), using the equipment of the Univ. Duisburg-Essen. Quite importantly, CeLight will co-package 90° hybrids and PIN-TIAs to minimize size and optical insertion loss. The various bias voltages of the 90° hybrid will be controlled with help of the data recovery circuit.

4. SiGe and CMOS electronic circuits and transmission testbed

A synchronous demodulation by a recovered carrier is needed to approach the ultimate sensitivity of 18 photons/bit. Early attempts to implement synchronous demodulation relied on phase-locked loops [1, 2]. The finite delay, a couple of nanoseconds at least, has required lasers with linewidths in the low kHz region. Such lasers require external resonators which are too expensive and large in size. However, the feedforward carrier recovery principle which led to the first synchronous PSK transmission with DFB lasers [11] can be extended to QPSK [3, 6], and this or similar principles have been verified by offline processing of oscilloscope-sampled experimental 10-Gbaud data streams [4, 5]. We intend to realize synchronous QPSK in a digital receiver, where inphase and quadrature data is sampled in 5-bit analog-digital converters (ADCs) at the clock rate (Fig. 1). An appropriate circuit (Fig. 4 left) has been designed by the Univ. Paderborn and has been fabricated in the 200-GHz SiGe process of IHP in Frankfurt/Oder (Germany).

A practical problem is the need to perform the digital signal processing in VLSI CMOS circuits, which work at $1/M$ of the symbol clock rate, where the demultiplex factor M may be 16 or so. We have therefore proposed a carrier recovery variant where the reduced processing rate does not impair the phase noise tolerance in any respect [7]. M identical CMOS "modules", which receive data from the ADCs and communicate also among each other, can perform this job, without time-critical paths. An appropriate CMOS chip has also been designed by the Univ. Paderborn, but chips have not yet been tested. In later versions, polarization control [8, 6] must also be included. It consists of an electronic multiplication of the inverse of the fiber Jones matrix $\mathbf{J}$ by the received Jones vector $\begin{bmatrix} R_1 & R_2 \end{bmatrix}^T \sim \mathbf{E}_{RX}$, and this can likewise be done at $1/M$-fold clock speed [7].

On the experimental side, we recently have a running synQPSK testbed where single-polarization QPSK is being transmitted at a speed of 400 Mbaud (800 Mbit/s) with standard DFB lasers (4 MHz intermediate frequency linewidth). Fig. 4 right shows a portion of a recovered 2^7-1 PRBS with no errors in the considered time interval. A bit error ratio of $6.3 \cdot 10^{-3}$ has been achieved for transmitted 2^{31}-1 PRBS. The validity of the employed concept for the intended future 10 Gbaud operation is thereby fully proven. Receiver bandwidth and noise still need to be improved by integrated photoreceivers, and analog-digital conversion and signal processing (in an FPGA) presently rely on low-speed commercial hardware. RZ coding may also be applied to optimize transmission performance.

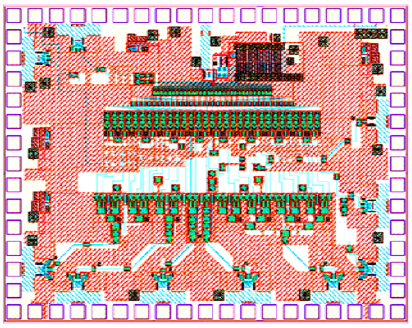

Fig. 4. Layout of a first prototypical 5-bit, 10 Gs/s analog digital converter (left). Portion of a recovered 2^7-1 PRBS after synchronous QPSK transmission with DFB lasers (right).

5. Conclusions

The planned European „synQPSK“ technology is challenging but tempting to solve several urgent problems of future lightwave communication systems. Due to its high performance we expect a lower cost per bit than for competing technologies. Project progress is on time.

6. References

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