Characterization of an Integrated Coherent Receiver for 224 Gb/s Polarization Multiplexed 16-QAM Transmission

Andreas Matiss[1], Markus Nölle[2], Johannes Karl Fischer[2], Christoph C. Leonhardt[1], Reinhold Ludwig[2], Jonas Hilt[2], Lutz Molle[2], Carsten Schmidt-Langhorst[2] and Colja Schubert[2]

[1]*u2t Photonics AG, Reuchlinstrasse 10/11, 10553 Berlin, Germany,*
Phone: +49 30 726 113-546, FAX: ++49 30 726 113-800, e-mail matiss@u2t.de
[2]*Fraunhofer Institute for Telecommunications, Heinrich Hertz Institute,*
Einsteinufer 37, D-10587 Berlin, Germany, e-mail: markus.noelle@hhi.fraunhofer.de

Abstract: An integrated coherent receiver module based on monolithically integrated 90° hybrids and balanced waveguide pin-photodiodes is presented. Optical transmission performance is demonstrated for a 224 Gb/s PDM 16-QAM modulated signal over 250 km ULAF.

OCIS codes: (250.3140) Integrated optoelectronic circuits; (040.5160) Photodetectors; (060.1660) Coherent communication

1. Introduction

In recent years, coherent detection and digital signal processing has become the most favorable receiver technology solution to enhance the available transport capacity in optical links [1]. The transmitting and receiving components for 100 Gb/s line rates over a 50 GHz channel grid have recently become commercially available. These components enable a combination of optical polarization multiplexing and quadrature phase shift keying resulting in a spectral efficiency of about 2 b/s/Hz for a 112 Gb/s link at 28 GBd symbol rate. For a further increase of channel capacity, the most promising modulation format is polarization multiplexed 16-level quadrature amplitude modulation (PDM 16-QAM), which allows for a spectral efficiency of 4 b/s/Hz, when transmitting at a symbol rate of 28 GBd over the 50 GHz channel grid.

In this work we demonstrate the transmission and detection of a 224-Gb/s PDM 16-QAM signal over an optical link of 250 km ultra-large effective area fiber (ULAF) using a small form factor integrated coherent receiver compliant to the CCRX-MSA package footprint. The achieved performance is compared to a discrete reference system and recent publications.

2. Integrated Optical Coherent Receiver

The core component of the integrated receiver are two optical 90° hybrids, each monolithically integrated with four waveguide pin-photodiodes in balanced configuration suited for o/e conversion with an electrical bandwidth of >30 GHz [2]. The 90° hybrids with the integrated pin-photodiodes are co-packaged into one module with four differential transimpedance amplifiers (TIA), used for linear amplification of the received signal up to differential output voltages of >1 Vpp.

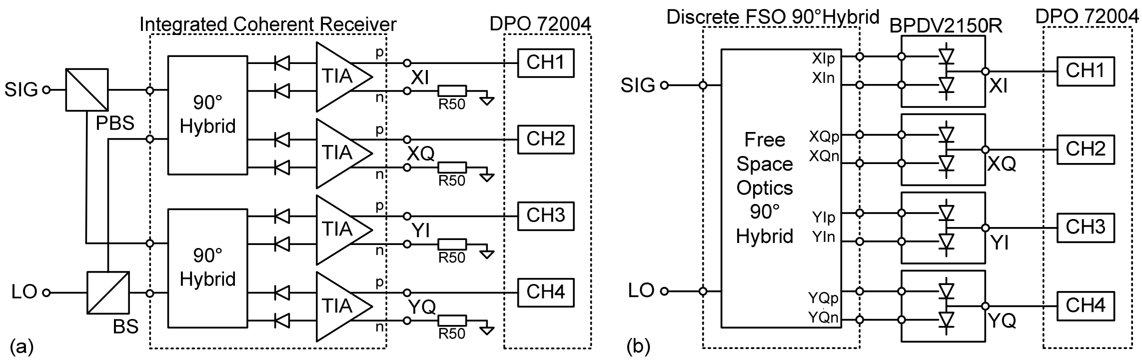

Fig. 1 (a) Integrated coherent receiver block diagram and reference setup (b) with discrete optical hybrid and balanced detectors

Fig. 1 (a) shows the principle block diagram of a complete setup for coherent reception of a PDM 16-QAM modulated data signal. The dashed rectangle indicates the integrated parts that are included in the coherent receiver module, which is illustrated by the picture in Fig. 2. The optical polarization beam splitter (PBS) and the beam splitter (BS) are not included in the receiver module. The package utilized a coplanar waveguide rf-interface for surface mount assembly of the device. The optical hybrids have been designed using a single, highly compact, multimode interference coupler (MMI) in a 2x4 I/O configuration [3]. For optimum performance in coherent systems the design of the photodiodes was optimized for balanced detection [4] and co-integrated with MMI and spot-size converters for lowest losses and almost zero skew between the tributary outputs in one polarization. The reference system consists of a discrete assembly utilizing four balanced detectors (BPDV2150R) with resistive single-ended outputs and a polarization diversity free-space optics 90° hybrid with fiber inputs and fiber outputs. All fiber links to the balanced receivers have been matched in length and in received optical power to allow for best common-mode rejection ratio of the balanced detectors.

3. System Measurement Setup

The experimental setup is depicted in Fig. 2. At the transmitter, an external cavity laser (ECL) with ~100 kHz linewidth is used as signal source. Using an optical polarization multiplexing stage (PMUX), the IQ modulated 16-QAM signals are polarization multiplexed. After polarization multiplexing, the PDM 16-QAM signal with a bit rate of 224 Gb/s is fed into a straight-line fiber link.

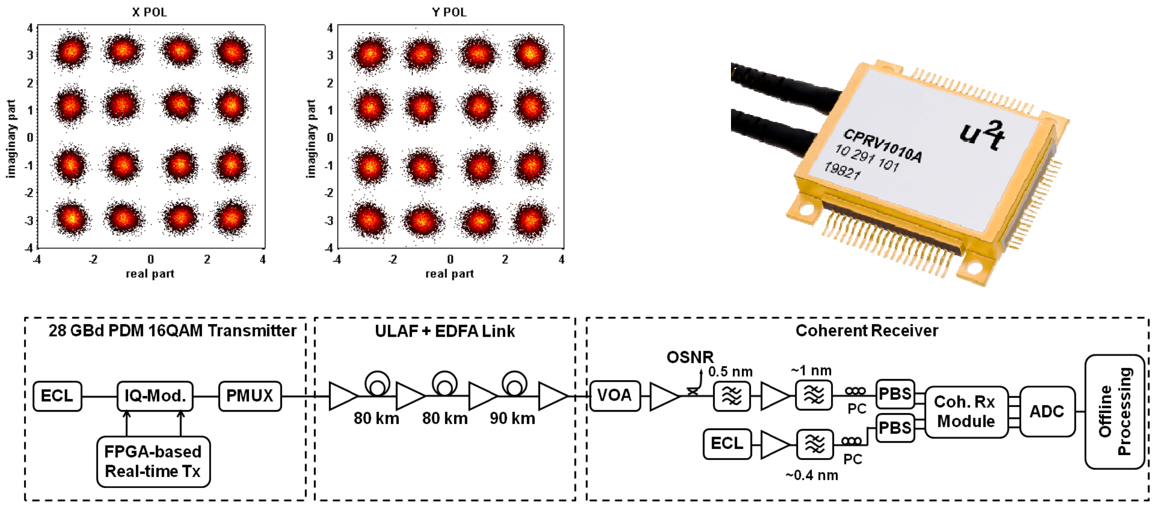

Fig. 2 Experimental setup for transmission of 28 GBd PDM 16-QAM signals over 250 km ULAF. Insets show recovered constellations at 37 dB OSNR in a back-to-back configuration (left) and a photograph of the integrated coherent receiver module.

The straight-line fiber link consists of three spans (80 km+ 80 km+ 90 km) of ULAF (kindly provided by OFS, Denmark). The loss of each fiber span is compensated by a preceding Erbium-doped fiber amplifier (EDFA). The residual chromatic dispersion after the fiber link amounts to about 5000 ps/nm, since no optical dispersion compensation is used. In the receiver, an EDFA-preamplifier and a variable optical attenuator (VOA) 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 by a 0.5 nm optical filter and boosted by a second EDFA. The average optical signal power per polarization tributary incident on the inputs of the coherent receiver module is –10 dBm. For the local oscillator a fixed power of 10 dBm for each LO input of the coherent receiver has been set. The post-processing algorithms include: resampling, correction of the 90°-hybrid phase errors and imbalance by using the Gram-Schmidt orthogonalization [5], frequency-domain chromatic dispersion compensation, skew correction and FFT based LO offset frequency correction [6]. 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 (CMA). After pre-convergence the error criterion is switched to the multi-modulus algorithm (MMA) described in [7] and finally the equalizer is switched to decision directed mode. After equalization the bits of the individual tributaries are decoded and errors are counted. A received PDM 16-QAM constellation diagram (back-to-back, 37 dB OSNR) is shown in Fig. 2 together with a photograph of the integrated coherent receiver module.

4. Results

The experimental results for the back-to-back case and for transmission of the PDM 16-QAM signal are shown in Fig. 3. The theoretical performance as well as the performance of the reference setup (a coherent receiver, built up with discrete components, as depicted in Fig. 1b) is shown in Fig. 3a. It exhibits an implementation penalty of about

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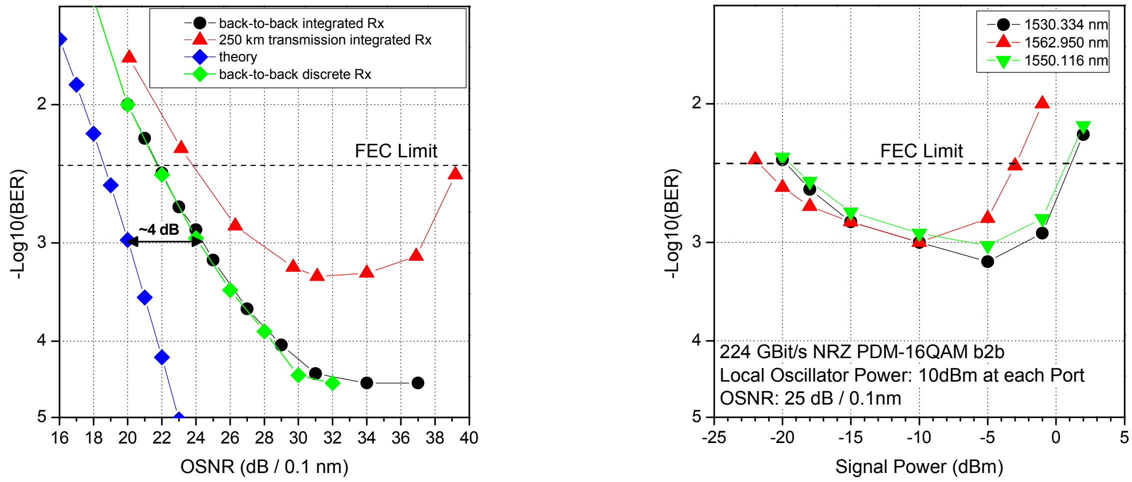
~4 dB at a bit-error rate of 10^{-3}. Furthermore, the b2b curve shows an error floor around 5 x 10^{-5}. A similar experiment with a discrete receiver setup has been demonstrated, showing a similar penalty of about 4.3 dB at a BER of 10^{-3} [8]. By varying the fiber input power between -9 and 9 dBm we were able to change the OSNR at the receiver between 20 and 40 dB. While the transmission performance at low OSNR values is limited by ASE noise, the fiber nonlinearities limit the performance in the high OSNR and by this high fiber input power case. It turned out that the optimum fiber input power for 250 km transmission is about 0 dBm, resulting in an OSNR of about 31 dB.



(a) (b)

Fig. 3 (a) BER versus OSNR for back-to-back case and after 250 km transmission over ULAF for PDM 16-QAM signals (theory and discrete setup for reference) and (b) receiver dynamic range for different wavelength and optical input power at fixed LO power.

In Fig. 3b, the incident signal power at the coherent receiver was varied between -20 dBm and +2 dBm while maintaining an OSNR of 25 dB resulting in a BER around 10^{-3}. The local oscillator power was keep constant at +10dBm input power. This power variation measurement has been carried out for the back-to-back case to characterize the dynamic range and the overload and sensitivity limits of the investigated receiver at different wavelength in the C-band. Assuming a constant OSNR of 25 dB, the receiver allows for error-free detection of 224 Gb/s PDM 16-QAM signals between approximately -20 dBm and -4 dBm optical input power at wavelengths 1530.334 nm and 1550.116 nm and between -22 dBm and -3 dBm at 1562.95 nm. Different overload and sensitivity limits at different wavelengths are attributed to the wavelength dependency of the photodiode responsivities. Compared to earlier results using 28 GBd PDM QPSK [2] the dynamic range is slightly decreased due to the higher sensitivity of PDM 16-QAM towards signal distortions.

4. Summary

We demonstrated the detection of a 224 Gb/s PDM 16-QAM signal using an integrated coherent receiver module. It has been shown that the integrated setup exhibits similar performance compared to discrete setups with optimized components. Due to the integrated linear transimpedance amplifiers the coherent receiver module has a large input power dynamic range between 19 dB and 24 dB in the C-band. Furthermore, we have successfully transmitted a 224 Gb/s PDM 16-QAM signal over 250 km ultra-large effective area fiber and by this demonstrated the potential of the integrated coherent receiver for 200 Gb/s transmission.

5. References

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