16-QAM Field-Quadrature Decomposition using Polarization-Assisted Phase Sensitive Amplification

Kjøller, Niels-Kristian; Piels, Molly; Da Ros, Francesco; Dalgaard, Kjeld; Galili, Michael; Oxenløwe, Leif Katsuo

Published in:
Proceedings of the 2016 IEEE Photonics Conference

Publication date:
2016

Document Version
Peer reviewed version

Link back to DTU Orbit

Citation (APA):
16-QAM Field-Quadrature Decomposition using Polarization-Assisted Phase Sensitive Amplification

N. K. Kjøller, M. Piels, F. Da Ros, K. Dalgaard, M. Galili and L. K. Oxenløwe
DTU Fotonik, Technical University of Denmark. DK-2800 Kgs. Lyngby, Denmark.

Abstract—Simultaneous I and Q extraction for 16-QAM is experimentally demonstrated through field-quadrature decomposition using a polarization-assisted phase sensitive amplifier. The quadrature components are successfully received and performance is evaluated through bit-error-ratio testing.

Keywords—optical signal processing; phase sensitive amplification; polarization-assisted phase sensitive amplification

I. INTRODUCTION
The use of spectrally efficient multilevel modulation formats such as m-level phase-shift keying (PSK) or quadrature amplitude modulation (QAM) has increased steadily in recent years. Nonlinear all-optical signal processing of such advanced modulation formats has attracted much attention, with the potential of energy and cost reductions over electronic processing [1]. Advantages include broad optical bandwidths and femtosecond response times, enabling ultrafast processing operations such as signal regeneration, wavelength conversion, and format conversion [2]. Electric field quadrature decomposition, extracting the in-phase (I) and quadrature (Q) components of an optical signal, is a useful operation for QAM modulated signals with possible applications in modulation format conversion. For 16-QAM it constitutes a building block towards conversion to four binary signals which would allow real-time direct-detection, or possibly all-optical regeneration through amplitude regeneration and coherent addition of the decomposed parts. Polarization-assisted phase sensitive amplification (PA-PSA) has been established as an effective technique for field quadrature decomposition, with demonstrated applications in regeneration of BPSK and QPSK signals and quadrature decomposition of QPSK signals [3–5].

In this paper we expand the application of PA-PSA and demonstrate experimentally the decomposition of a 16-QAM signal, separating its I and Q components. Simultaneous extraction of the I and Q components is verified and bit-error-rate (BER) performance is evaluated for the decomposed signals.

II. PRINCIPLE
As demonstrated in [3–5], PA-PSA involves coherently mixing the signal and idler of a dual pump degenerate vector PSA in a polarizer, as shown in Fig. 1. By adjusting the transmission axis of the polarizer, the signal (S) and its phase conjugated idler (S*) are added or subtracted with equal amplitude in order to yield the I or Q component of the signal. For 16-QAM the resulting outputs are modulated in a format having two amplitude levels (±1 and ±2 of the average output amplitude) and two phase levels (0 and π). This format will be referred to as 4 amplitude-phase-shift keying (4-APSK).

III. EXPERIMENTAL DEMONSTRATION AND RESULTS
In order to investigate the performance experimentally, the setup in Fig. 2 was constructed. Three phase-locked carriers P1 (1538 nm), S (1544 nm), and P2 (1550 nm) to be used...
for the PSA stage are generated using four wave mixing in a 500 m highly nonlinear fiber with stable phase-matching for improved non-linear efficiency (HNLF-SPINE). The signal carrier S and the pumps P1, P2 are separated using an optical processor. S is modulated at 10 Gb/s with a 16-QAM signal consisting of pseudo-random bit sequences (PRBSs) of lengths $2^{23} - 1$ and $2^{15} - 1$ in the I and Q components, using a standard IQ modulator. The signal and pumps are recombined and their polarizations are adjusted so that P1 and S are parallel and orthogonal to P2. The separate path lengths are equalized by inserting ~5 m of standard single mode fiber. Slow thermal drifts of the relative phases are compensated by an active feed-back phase-control loop based on a low speed avalanche photodiode and a piezoelectric actuator. PSA takes place in a strained 250 m HNLF-SPINE, with the input and output spectra shown in Fig. 3(a). A total input power of 24 dBm and a pump to signal power ratio of 10 dB results in the creation of a phase conjugated idler with a conversion efficiency of -5.1 dB. The pumps are removed using an optical bandpass filter and the orthogonal signal-idler pair is mixed simultaneously in two polarizers aligned to yield the I and Q components. A static phase sensitive extinction ratio of 22.8 dB is observed. The two outputs are passed through a noise loading stage to a coherent receiver and digital storage oscilloscope for offline signal processing. This consisted of clock recovery, radius-directed adaptive equalization using the cost function modification suggested in [7], and carrier recovery using a decision-directed phase-locked loop.

In Fig. 3(b) the measured constellation diagrams are shown for the 16-QAM input and the decomposed I and Q outputs. After quadrature decomposition the $2^{23} - 1$ and $2^{15} - 1$ PRBSs are recovered on the I and Q components respectively, verifying simultaneous extraction of both I and Q. BER is measured for the 16-QAM input B2B (black) and for the 4-APSK modulated I and Q outputs (grey), as seen in Fig. 3(c). For each point a total of 2.46e6 symbols are counted, allowing estimation of BERs down to $10^{-5}$ with at least 100 counted errors. Points have been included below BER = $10^{-5}$ with error counts down to 13, corresponding to 99% probability for the actual BER being within a factor of two [8]. We observe that the field-quadrature decomposition results in a penalty of the SNR required for BER = $10^{-2}$ of around 1.5 dB, increasing to around 5 dB for the I and 6 dB for the Q components for BER = $10^{-5}$.

IV. CONCLUSION

We have expanded the application of polarization-assisted phase sensitive amplification, and demonstrated electric field-quadrature decomposition of a 16-QAM signal at 10 Gb/s. We successfully extract the two quadrature components (I and Q) simultaneously. The BER performance have been evaluated and we report SNR penalties of 1.5 dB at BER = $10^{-2}$, increasing to 5 dB for the I and 6 dB for the Q components at BER = $10^{-5}$.

ACKNOWLEDGMENT

Danish Council for Independent Research (FTP) for funding the TOR project (grant no. 12-127224), and OFS Fitel Denmark ApS for providing the HNLF-SPINEs.

REFERENCES