Electronic Dispersion Compensation for 107Gb/s Coherent Detection with Multi-Level Modulation Formats

Christina Hebebrand and Werner Rosenkranz
Chair for communications, University of Kiel, Kaiserstr. 2, 24143 Kiel, Germany, ch@tf.uni-kiel.de

Abstract *We investigate the performance of electronic dispersion compensation for coherent detection with a zero-forcing equalizer approach, using the minimum mean-square error criterion, for RZ-QPSK, RZ-8PSK and Star-RZ-16QAM for the linear and nonlinear channel at 107Gb/s.*

Introduction

The next bitrate in the Ethernet hierarchy is expected to be 100Gb/s. For this, multi-level modulation formats can be used to reduce the bandwidth requirement. In conjunction with a coherent receiver the multi-level formats can be demodulated in the electrical domain with digital signal processing (DSP), due to the availability of high-speed digital signal processors. Similarly carrier and phase recovery as well as the equalization can be done by the DSP [1].

In this contribution we investigate numerically the performance of electronic dispersion compensation (EDC) after coherent reception for RZ-QPSK, RZ-8PSK and Star-RZ-16QAM at 107Gb/s for the linear and nonlinear channel. EDC is achieved by a zero-forcing (ZF) approach, using the minimum mean-square error (MMSE) criterion to derive the coefficients. We investigate the performance in terms of dispersion tolerance by Monte-Carlo simulations.

Simulation setup

At the transmitter side either 53.5Gbaud RZ-QPSK [2], 35.7Gbaud RZ-8PSK [3] or 26.75Gbaud Star-RZ-16QAM are generated to achieve 107Gb/s for all modulation formats according to fig. 1 (top). Star-RZ-16QAM is generated from RZ-8PSK with an additional Mach-Zehnder modulator (MZM). The advantage of this setup is the necessity of only binary driving signals, contrary to multi-level driving signals in the case of pure I/Q-modulation. All data signals are differentially encoded due to the phase ambiguity.

The transmission channel is modelled as a single span with variable length to adjust the chromatic dispersion (CD). A linear channel (only CD, D=17ps/nm/km) as well as a nonlinear channel (self-phase-modulation (SPM) and CD, γ=1.6215 1/W/km, α=0.21dB/km, $P_{\text{fiber in, average}}$=5dBm) is assumed.

At the receiver side an EDFA with a Gaussian optical bandpass filter (BP, f_{3dB}= 4.1x baudrate) is used for noise loading. The received signal is combined with the signal of a local oscillator (LO) in a 2x4 90º hybrid (for this contribution ideal homodyne detection is assumed) and detected with two balanced photo-detectors. Afterwards the resulting electrical inphase and quadrature signals are lowpass (LP) filtered (Butterworth 3^{rd} order, f_{3dB}= 1x baudrate), sampled twice per symbol and then processed in a digital signal processing unit (fig. 2).

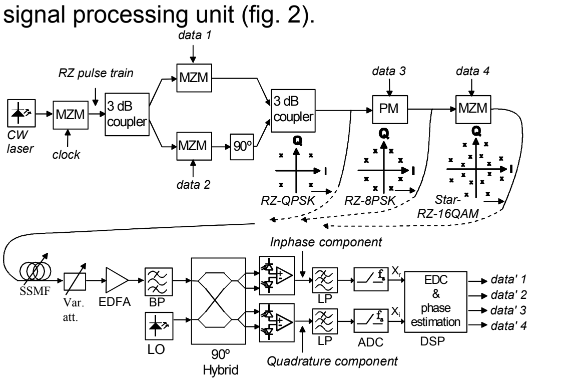

Fig. 1: Transceiver (top), channel and receiver (bottom) setup; PM: Phase Modulator;

For EDC, linear transversal filters for all investigated equalizer are used. The performance of equalizer with only a feed forward filter (FFE[*x*], where *x* denotes the number of filter coefficients) and with an additional decision feedback equalizer (DFE[x], where feedback of the decision to the EDC is necessary (fig.2)) are examined. The equalizer has a complex baseband structure and the coefficients are determined with a ZF approach based on the MMSE criterion with the use of a training sequence [4].

The symbol decision in the DSP is made on phases with an additional decision on the amplitude for Star-RZ-16QAM. After decision the differential decoding and mapping into two, three or four data streams (depending on the modulation format) takes place.

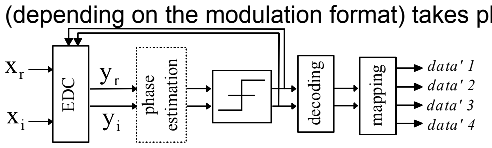

Fig. 2: Digital signal processing unit for a 16-level modulation format

Results and discussion

Fig. 3 shows the OSNR penalty at a BER of 10^{-4} versus CD without EDC for all modulation formats for the linear and nonlinear channel.

Due to the short transmission distances the effective nonlinear length is small and therefore the influence of the nonlinear effects is small as well. The dispersion tolerance for RZ-QPSK (53.5Gbaud) and RZ-8PSK (35.7Gbaud) is almost equal. Obviously the expected improvement due to the reduced bandwidth of RZ-8PSK is just compensated for by the narrower symbol spacing. For Star-RZ-16QAM (26.75Gbaud) the bandwidth is reduced further, whereas the minimum distance of the double-ring constellation is reduced only slightly compared to RZ-8PSK.

a)

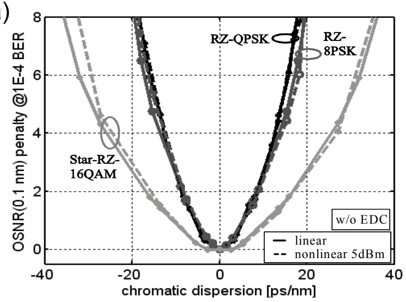

Fig. 3: OSNR penalty vs. CD without EDC for RZ-QPSK, RZ-8PSK and Star-RZ-16QAM for the linear (solid) and the nonlinear (dashed) channel.

Now, EDC with the ZF-equalizer for the linear channel is applied (fig. 4). First of all an improvement of at least one order of magnitude can be observed (note the abscissa scales of fig. 3 and 4). Comparing the various modulation formats the dispersion tolerance increases with decreasing bandwidth. For each modulation format the dispersion tolerance can be enlarged further by increasing the equalizer filter length. For Star-RZ-16QAM e.g. the dispersion tolerance at 2dB OSNR penalty can be increased from ±550ps/nm with FFE[9] to greater than ±800 ps/nm with FFE[15]. However in general the overall improvement with an additional DFE is rather small.

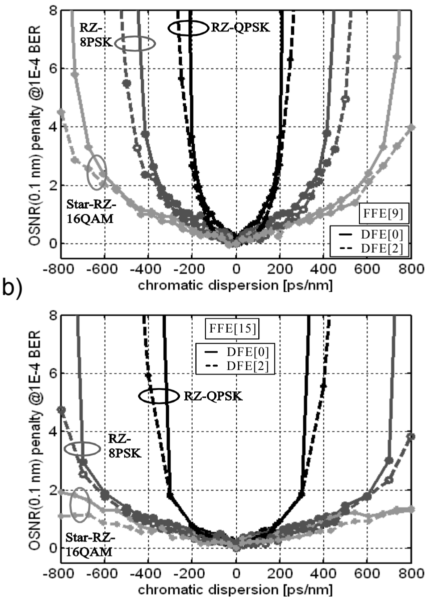

Fig. 4: OSNR penalty vs. CD for the linear channel for RZ-QPSK, RZ-8PSK and Star-RZ-16QAM for a) FFE[9] and b) FFE[15] without DFE (DFE[0], solid) and with DFE 2nd order (DFE[2], dashed).

Fig. 5 depicts the performance of the ZF-equalizer for the nonlinear channel. For RZ-QPSK and RZ-8PSK the performance is almost the same as for the linear case. However for Star-RZ-16QAM the dispersion tolerance degrades compared to the linear case. Here the equalizer design has to consider the different SPM induced nonlinear phase shifts of the two amplitude rings. The determined coefficients are a compromise for the compensation of both phase shifts. Thus for such multi-ring constellations equalization should be supported by a compensation of the nonlinear phase shift (as e.g. proposed in [5]).

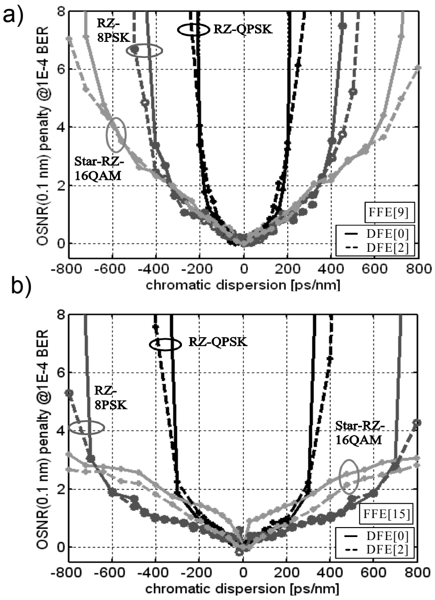

Fig. 6: OSNR penalty vs. CD for the nonlinear channel for RZ-QPSK, RZ-8PSK and Star-RZ-16QAM for a) FFE[9] and b) FFE[15] without DFE (DFE[0], solid) and with DFE 2nd order (DFE[2], dashed).

Conclusions

We investigated the performance of EDC in conjunction with coherent reception for RZ-QPSK, RZ-8PSK and Star-RZ-16QAM for the linear and nonlinear channel at 107Gb/s. For EDC a zero-forcing equalizer is applied, using the MMSE criterion for deriving the coefficients. Only for Star-RZ-16QAM we find a degraded dispersion tolerance of the nonlinear channel compared to the linear case. Nevertheless for Star-RZ-16QAM a dispersion tolerance (at 2dB OSNR penalty) of the linear channel of ±550ps/nm with FFE[9] and greater than ±800ps/nm with FFE[15] can be achieved. For the nonlinear channel still ±350ps/nm is obtained. For this channel RZ-8PSK is most robust with ±550ps/nm, which is equivalent to a transmission of about 32km over SSMF.

References

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