Simultaneous Adaptive Equalization of Group Velocity and Polarization Mode Dispersion at 40Gb/s with Integrated Optical FIR-Filters and Electrical Spectrum Monitoring as Feedback

Marc Bohn (1), Folkert Horst, Bert Jan Offrein, Gian Luca Bona (2), Werner Rosenkranz (1) , Peter Krummrich (3)
1 : University of Kiel, Chair for Communications, Kaiserstr. 2, 24143 Kiel, Germany, E-mail: mbo@tf.uni-kiel.de
2 : IBM Research, Zürich Research Laboratory, E-mail: fho@zurich.ibm.com
3 : Optical Networks Advanced Technology, Siemens AG, E-mail: peter.krummrich@siemens.com

Abstract *In contrast to time domain equalization criteria (BER, eye monitoring), strategies using the electrical spectrum are fast, easy and inexpensive to implement. We present a monitoring strategy of a single frequency for combined adaptive GVD and PMD mitigation at 40Gb/s with integrated optical FIR-Filters.*

Introduction

In high bitrate optical transmission systems group velocity dispersion (GVD) and polarization mode dispersion (PMD) compensation are critical aspects.
With increasing bitrates GVD tolerances will be smaller than the temporal dispersion fluctuations in the system, e.g. due to rerouting or temperature and power variations. A tolerance of a maximum mean PMD of 10% of the bit length is recommended, which is easily exceeded with increasing bitrates. Therefore, to meet the tolerances and to compensate for these time varying distortions an adaptive tuneable GVD and PMD compensating device and a fast, easy and inexpensive criterion for the adaptive feedback is needed. Integrated optical FIR-Filters can compensate for both, GVD /1/ and PMD /2/.
As criterion for the adaptive control, solutions in the time as well as in the frequency domain have been proposed. Time domain criteria are e.g. the Intersymbol Interference, Eye Opening, Q-Factor or Bit Error Rates. Optical approaches in the frequency domain are e.g. vestigal side band filtering /3/, spectral broadening through a Kerr nonlinearity /4/ or monitoring a subcarrier /5/.
As signal distortions due to the transmission fiber can be determined very well in the electrical spectrum, a fast, inexpensive and easy to implement solution is to monitor frequencies in the electrical spectrum of the received signal. By monitoring the power of a single frequency component f_0, we get a 2 dimensional space depending on GVD and PMD with a global maximum at zero GVD and PMD. Moreover distortions due to Self-Phase Modulation (SPM) or laser chirp will be compensated by balancing SPM and GVD into an optimum. Monitoring two or more frequencies prevent from tracking a local maximum. The spectral monitoring can be easily implemented by bandpass filters.
The principle of the simultaneous adaptive equalization of both, GVD and PMD at 40Gb/s with a single feedback criterion, is proven by simulation results. The adaptive compensation of GVD at 40Gb/s is demonstrated in an experiment.

System

In order to evaluate the adaptive optical equalizing strategy by monitoring frequencies within the electrical spectrum of the received signal, the setup of Fig.1 is used. A 40Gb/s NRZ signal at 193.1THz is distorted by different values of GVD from SSMF and DCF of variable length. A PMD emulator sets the desired PMD value.
The compensating device, the 6^{th} order optical FIR-Filter, is based on a lattice structure, which is integrated by cascading symmetrical and asymmetrical Mach-Zehnder Interferometer (MZI) in a planar lightwave circuit (PLC). The device is designed and fabricated by IBM using the high index contrast SiON technology /6/. Equalization is achieved by controlling the coupling ratios and the phase

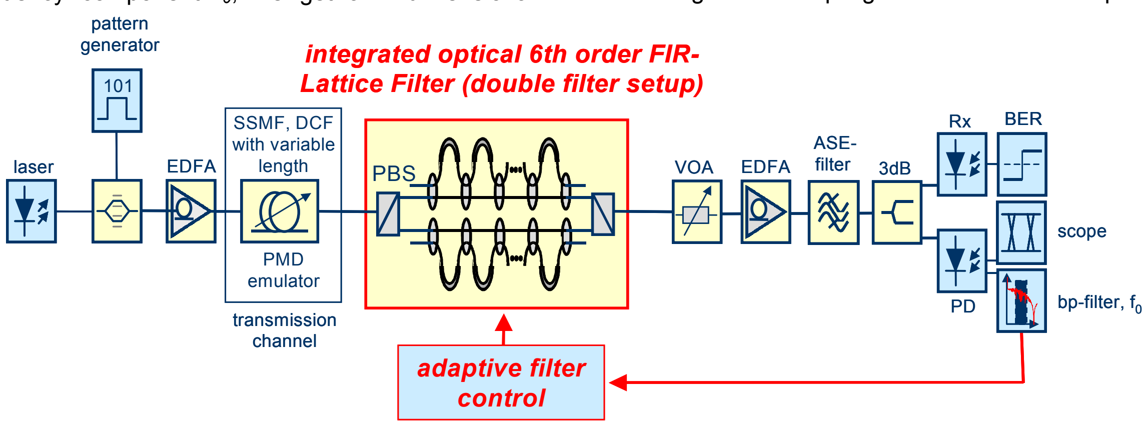

Figure 1: System setup: Simultaneous adaptive GVD and PMD compensation at 40Gb/s

differences of the interfering signals. While compensating GVD, a single filter is sufficient. For compensating both, GVD and PMD, the best setup is to split the orthogonal polarization modes by a polarization beam splitter (PBS) and equalize each mode with a separate filter, Fig.1.

At the receiver, the electrical signal is bandpass filtered at a center frequency f_0 and the detected power is used as feedback signal for the adaptive control to compensate for GVD and PMD.

Results and Discussion

Signal distortions are determined through changes of the transfer function of the optical fiber. The optical fiber transfer function is reflected in the power spectral density or the electrical spectrum of the received signal. These changes due to GVD and PMD are measured with a bandpass filter at center frequencies $f_0=10,20,40GHz$ and are used as feedback for the adaptive control and compensation.

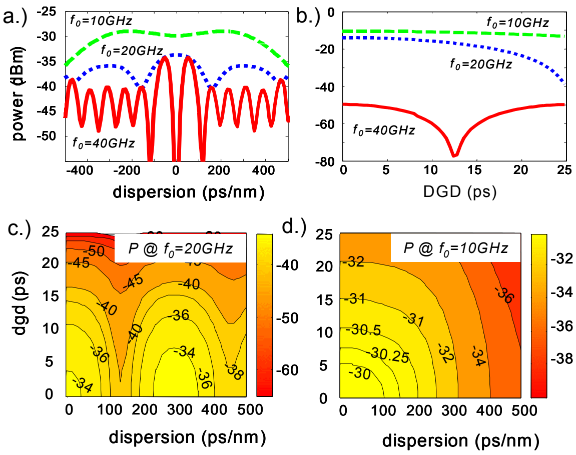

Figure 2: Power response of the bp-filtered el. signal at f_0=10,20,40GHz, a.) GVD, b.) PMD, GVD & PMD at c.) f_0=20GHz, d.) f_0=10GHz

Monitoring the power of the bandpass filtered received electrical signal for varying dispersion values leads to an oscillating signal with a global maximum ($f_0<f_{bit}$) or minimum ($f_0=f_{bit}$) at zero dispersion for linear transmission, Fig.2a. The bandpass filtered electrical PMD signal leads to well defined alternating power maxima and minima /7/ at a differential group delay (DGD) of e.g. n-times $T_{bit}/2$ for a center frequency of $f_0=40GHz$, Fig.2b. Combining both signal distortions, PMD and GVD, one gets a 2 dimensional space with a global maximum at zero dispersion and zero PMD, Fig 2c,d. To avoid tracking a local maximum and extend the range in which the adaptation works properly, one should monitor more than one frequency f_0.

The adaptive compensation of GVD with monitoring the bandpass filtered received electrical signal ($f_0=20GHz$) as feedback signal and using our integrated optical 6th order FIR-Lattice filter is demonstrated in an experiment, Fig.3.

From a starting point of $D=120ps/nm$ residual

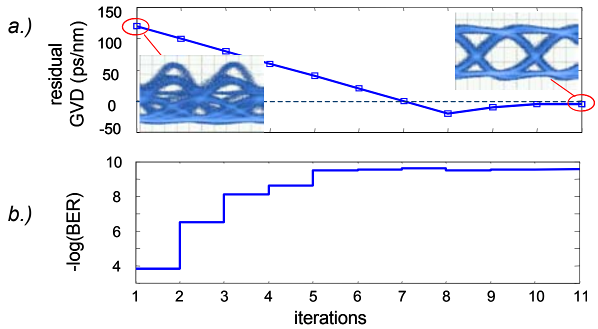

Figure 3: adaptive GVD compensation results a.)residual GVD values=channel+equalizer, eye pattern; b.) BER

dispersion (BER<10^{-4}), the adaptive control algorithm varies the overall dispersion (channel+equalizer) slightly to detect the optimization direction. The actual step is compared with the previous one. If the power of the bp-filtered el. signal is getting lower, the optimization direction is changed and the step size is halved until the optimum value is reached.

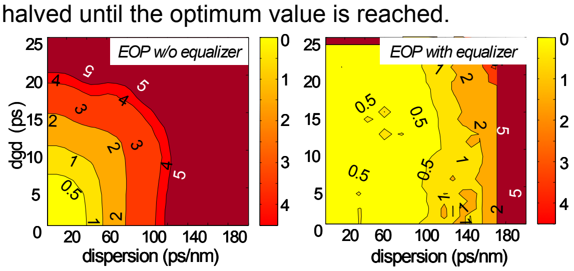

Figure 4: Simultaneous adaptive compensation of GVD & PMD, EOP w/o and with equalizer

The combined adaptive compensation of GVD and PMD with a feedback signal from electrical spectrum monitoring ($f_0=20GHz$) and our optical FIR-lattice filter in the double filter setup is shown by simulations, Fig.4. The adaptation works up to values for GVD of *170ps/nm* and DGD of *24ps*, the eye opening penalty (EOP) is well reduced. Higher values converge to a local maximum. To increase the range, the monitoring of a second (lower) frequency is necessary.

Conclusions

The experimental and simulation results prove that monitoring frequencies within the electrical spectrum of the received signal is very well suitable for a combined adaptive compensation of GVD and PMD. This feedback criterion is fast, inexpensive and easy to implement. Further on, the integrated optical FIR-filter in the double filter setup allows a simultaneous compensation of GVD and PMD in one single device.

References

1 M. Bohn et al., ECOC proc., 2002, Tu 4.2.3
2 M. Bohn et al., NFOEC proc., 2002, We D6
3 Q. Yu et al., OFC proc., 2002, We3
4 P. Westbrook et al., IEEE PTL, Vol.14, No.3, 2002
5 M. Petersen et al., OFC proc., 2000, WH4-1
6 R. Germann et al., J. of Electrochem. Society, 11 (1999), pp. 2237-2241
7 R. Noe et al., J. Lightw. Tech., Vol.17, No.9, 1999