Leistungsfähigkeit von elektronischen Entzerrer in hochbitratigen optischen Übertragungssystemen

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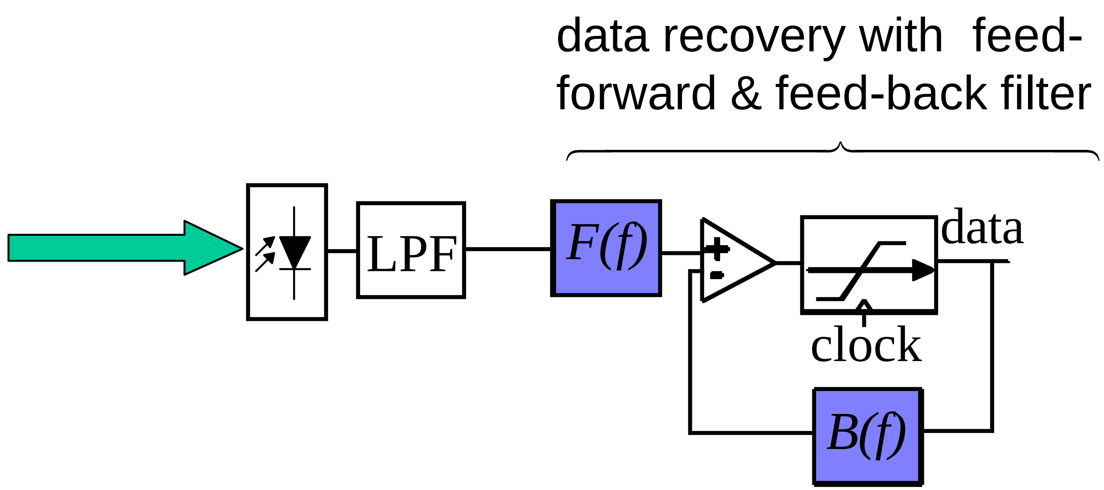
Outline

1. Motivation
2. Overview of Impairments: Chromatic Dispersion & SPM and PMD
3. Nonlinear Signal Components within electrical receiving Signal
4. Electronic equalizer approaches
5. Adaptive realization
6. Experimental results for Chromatic dispersion & SPM
7. Results for PMD
8. Summary

Why Electronic Equalization?

- chromatic dispersion
- PMD
- nonlinear effects



application:

- compensate for dispersion and nonlinear effects
  - in WDM-links with DCF to compensate for residual dispersion
  - in the nonlinear power regime of the fiber
- compensate for PMD+GVD+SPM independent from physical origins
- standard adaptive algorithm available

in general less cost intensive then optical compensator

hardware implementation on receiver-IC combined with clock & data recovery

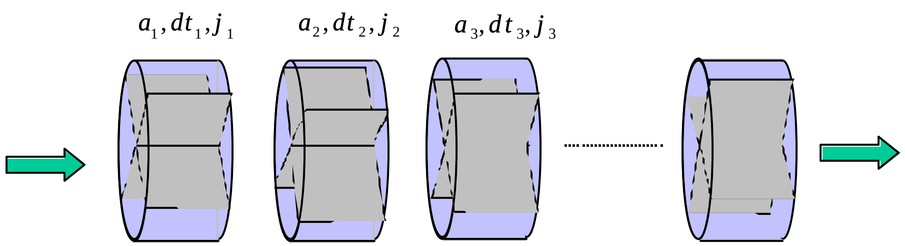
Fiber Impairments

- chromatic dispersion (GVD) (Pulse broadening due to group velocity dispersion, square dependence)

$$H(f) \approx const \cdot e^{\, j2p \frac{D l L}{2c} f^{2}}$$

D=17ps/nm km for SSMF

- polarization mode dispersion (PMD) (differential group delay, mode coupling)



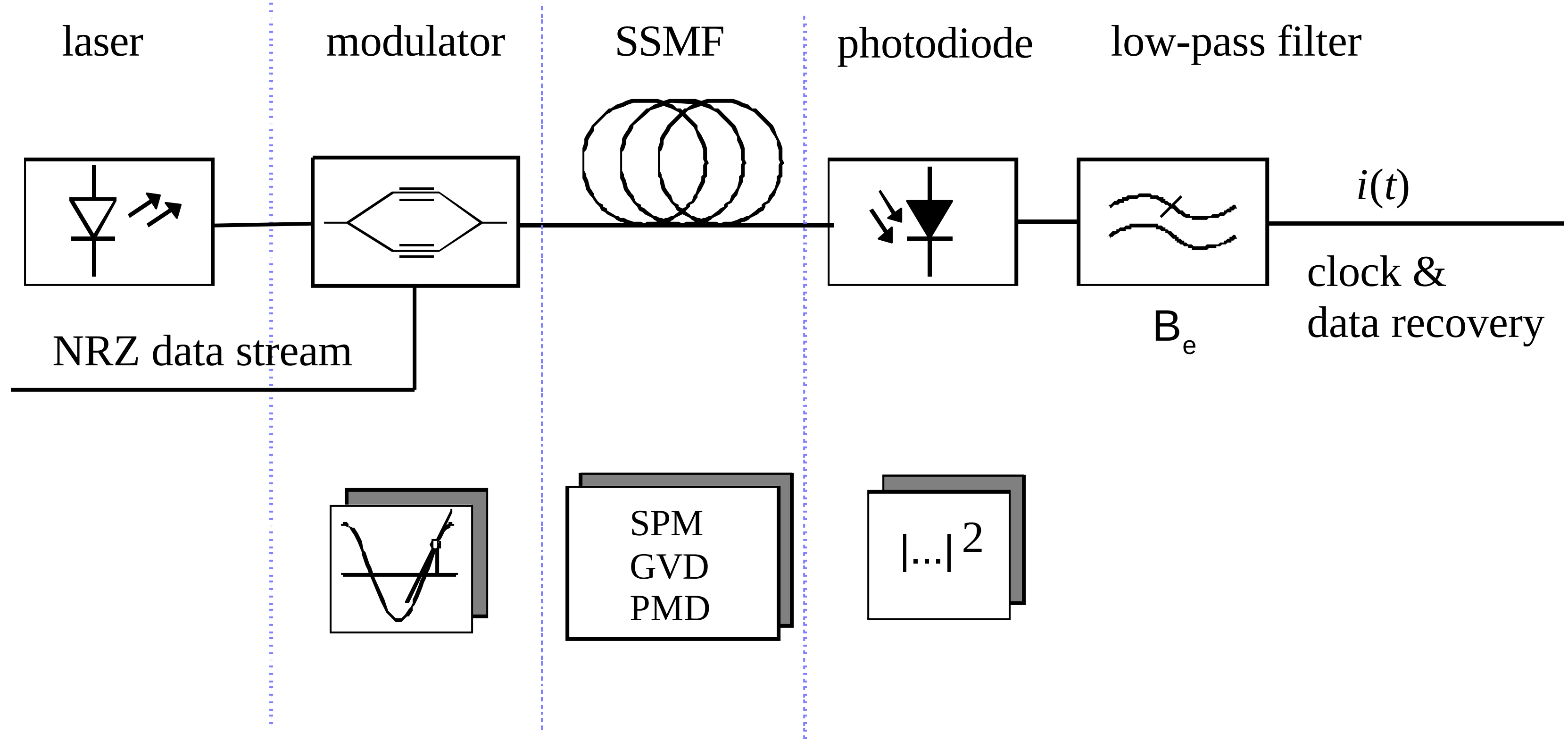
wave-plate model, Δτ, γ

- self phase modulation (SPM)

$$\frac{\partial A}{\partial z} + \frac{\alpha}{2} A - j \frac{\beta_2}{2} \frac{\partial^2 A}{\partial t^2} = -j\gamma \left| A \right|^2 A$$

nonlinear Schrödinger-equation

Optical Single Channel Transmission System



amount of nonlinear distortions ?

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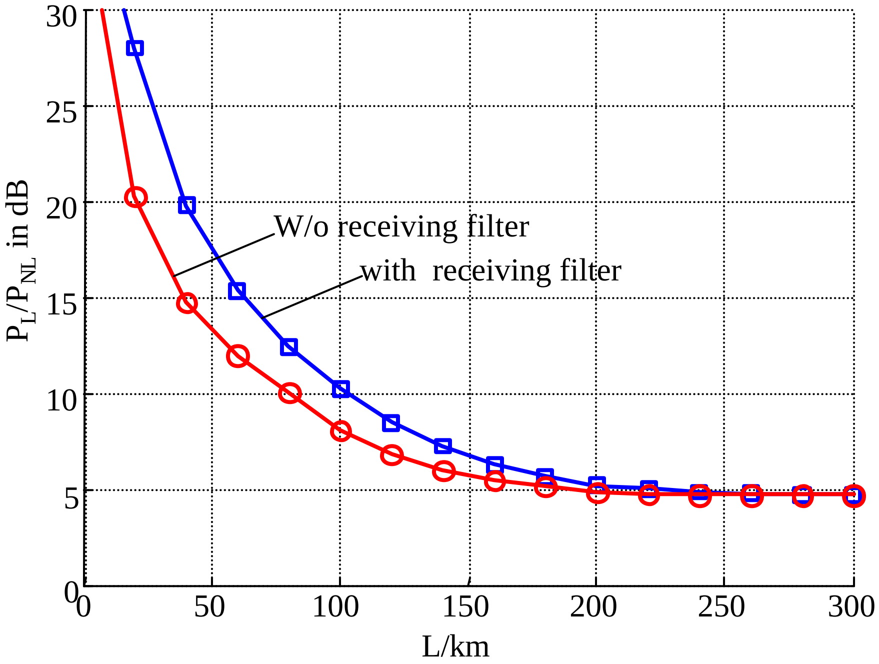
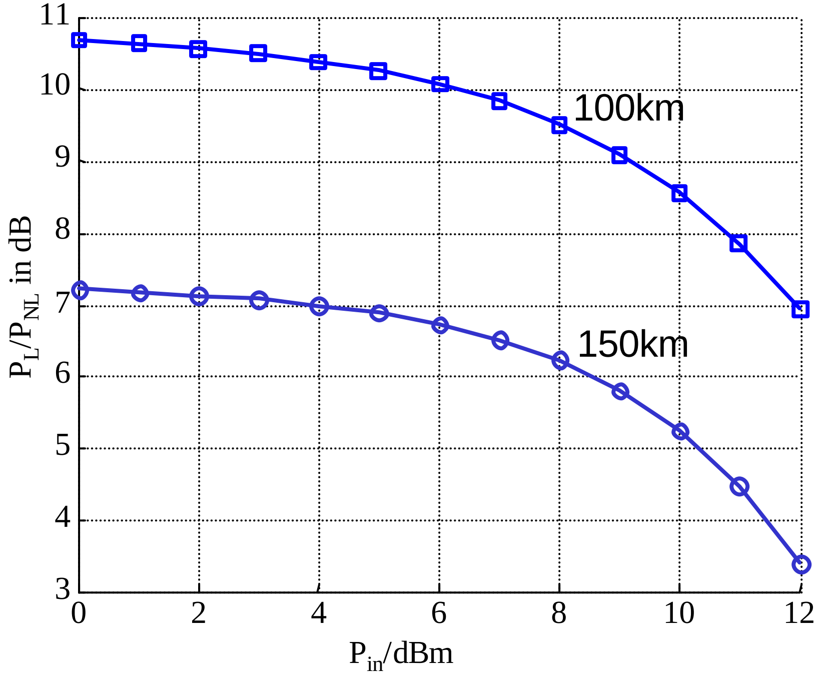
Nonlinear Signal components within the electrical receiving signal for GVD and SPM

Volterra-series model: $y_{receive}(t) = y_{linear}(t) + y_{nonlinear}(t)$

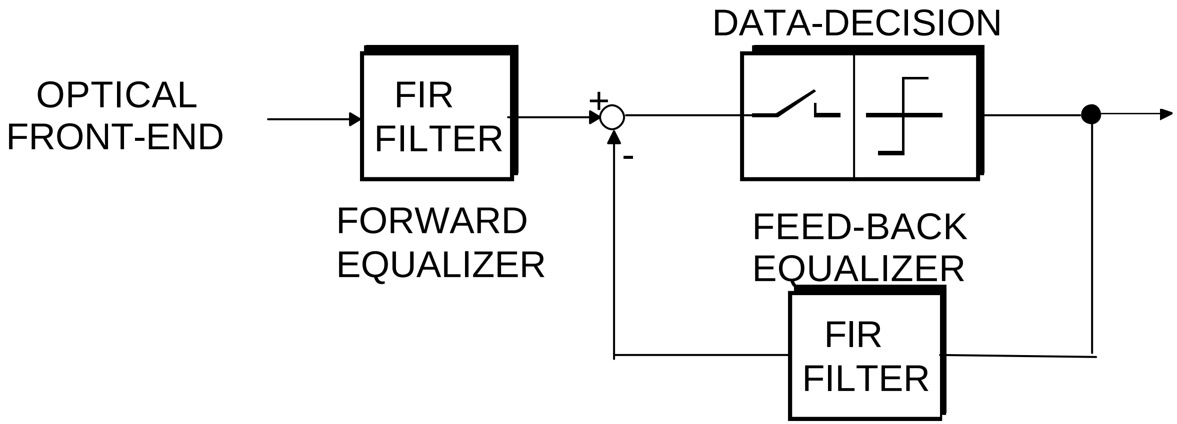
Ratio of linear signal components to nonlinear signal components vs. fiber length (17ps/nm/km) for linear fiber behavior



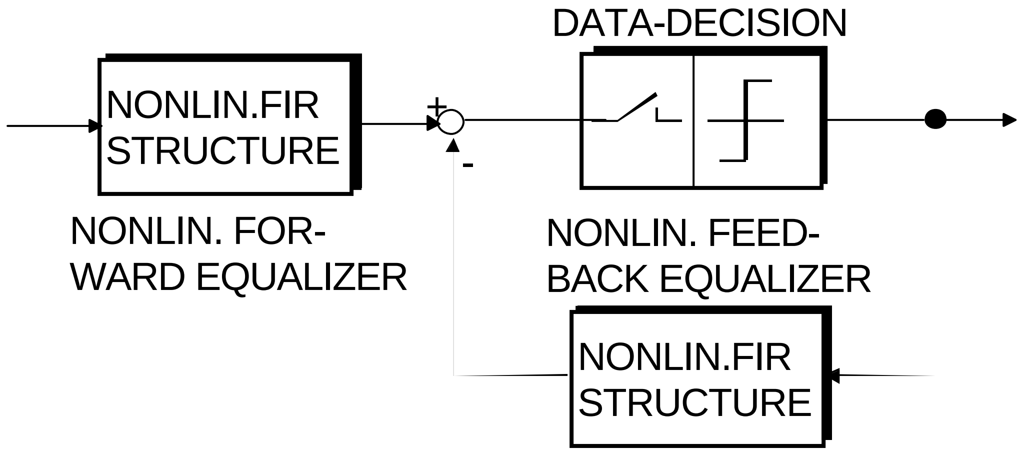
Ratio of linear signal components to nonlinear signal components vs. mean optical input power at 100&150km



Electronic Equalizer Approaches

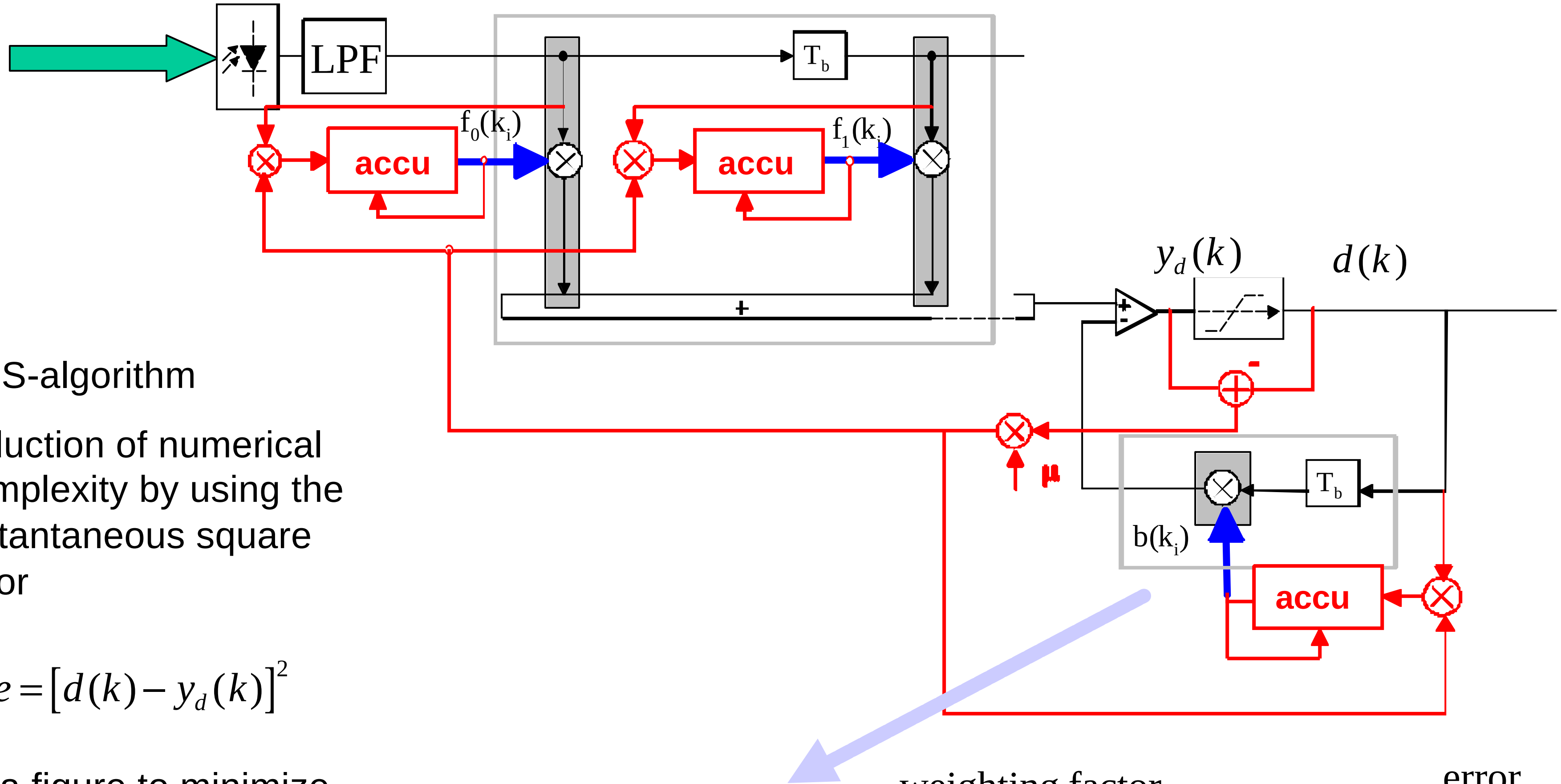


FIR-DFE: feed-back & feed-forward filter in order to compensate for precursor ISI



NL-FIR-DFE: nonlinear processing based on Volterra theory within forward and backward branch in order to compensate for nonlinear distortions

Adaptive Equalizer Implementation (LMS-algorithm)



LMS-algorithm

reduction of numerical complexity by using the instantaneous square error

$$se = [d(k) - y_d(k)]^2$$

as a figure to minimize resulting in a simplified expression for the gradient

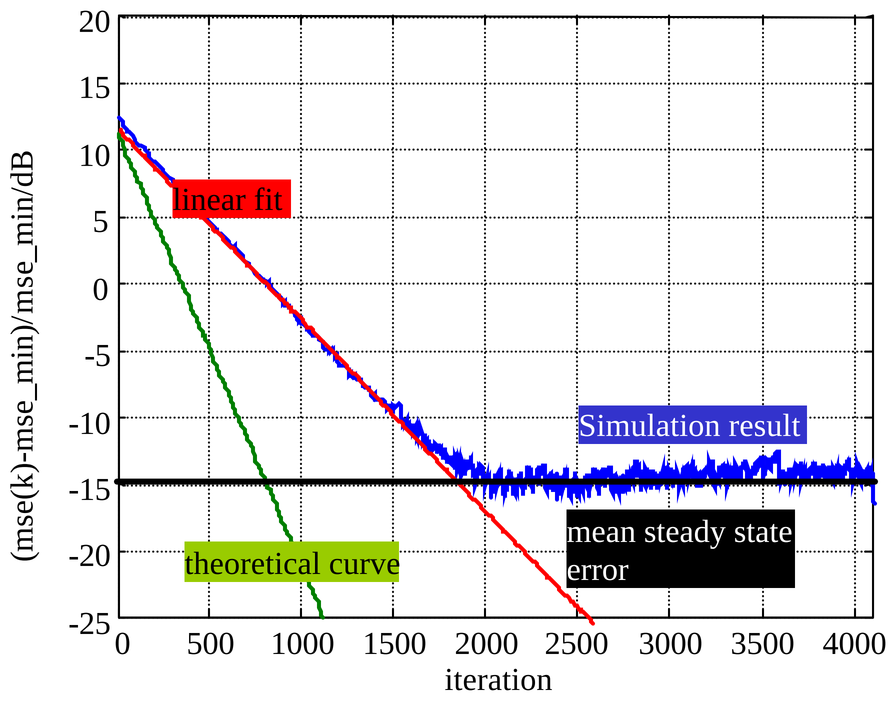
$$b(k+1) = b(k) + \overbrace{m}^{\text{weighting factor}} \underbrace{d(k-1)}_{\text{eq.state}} \overbrace{[d(k) - y_d(t_0 + k)]}^{\text{error}}$$

Properties of LMS-Adaptation Process

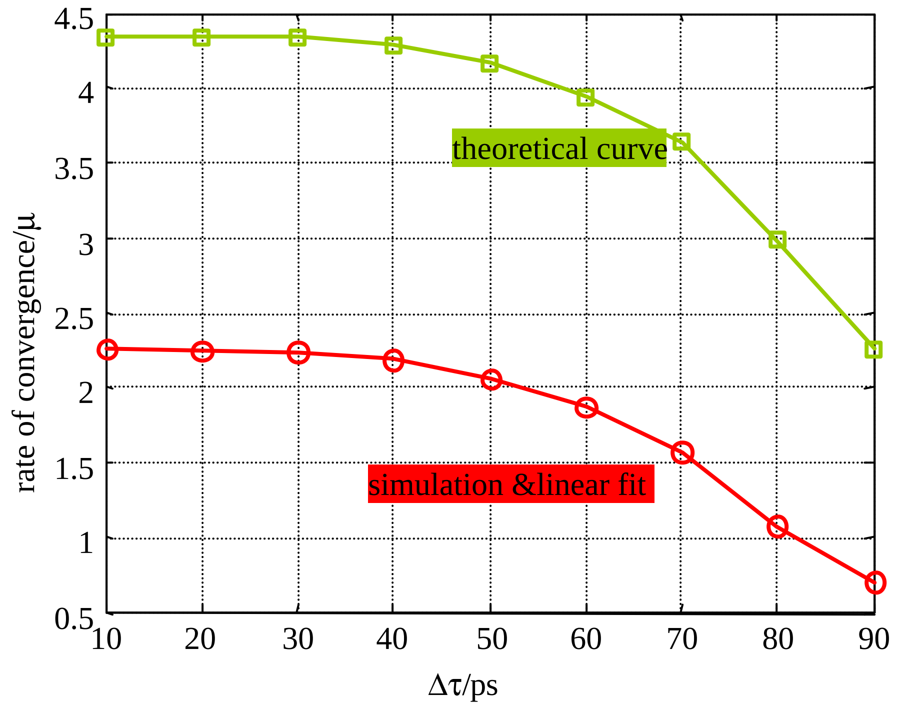
Comparison between theoretical and simulated acquisition behavior of a

2 tap synchronous equalizer under first order PMD distortions

Residual error vs. number of iterations at $\Delta\tau$=80ps



Convergence rate vs. DGD



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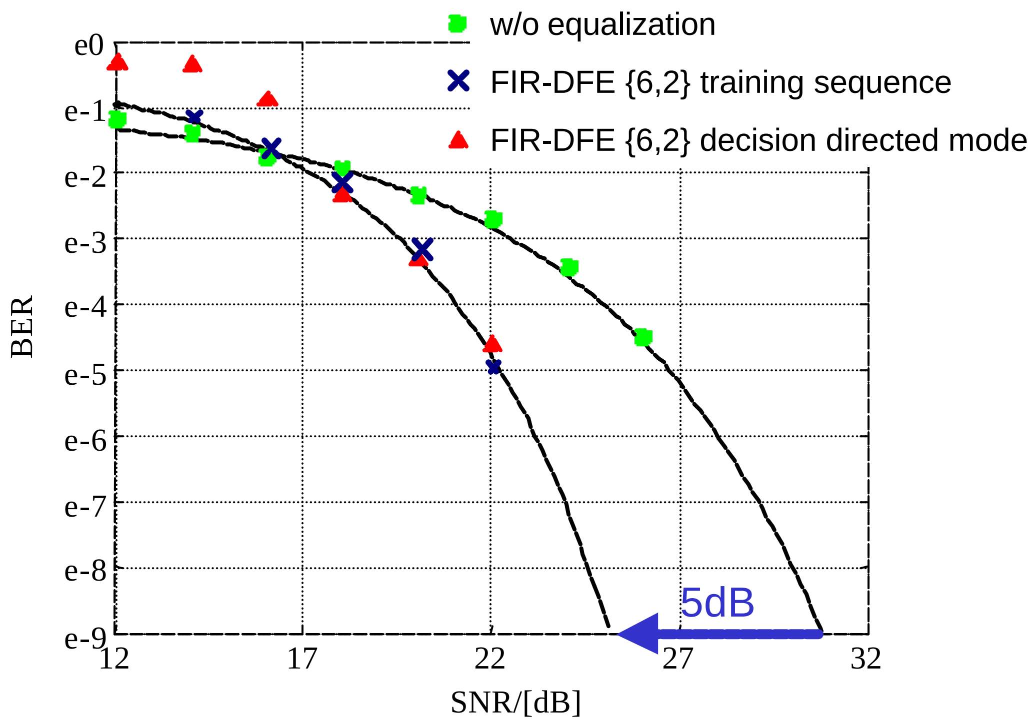
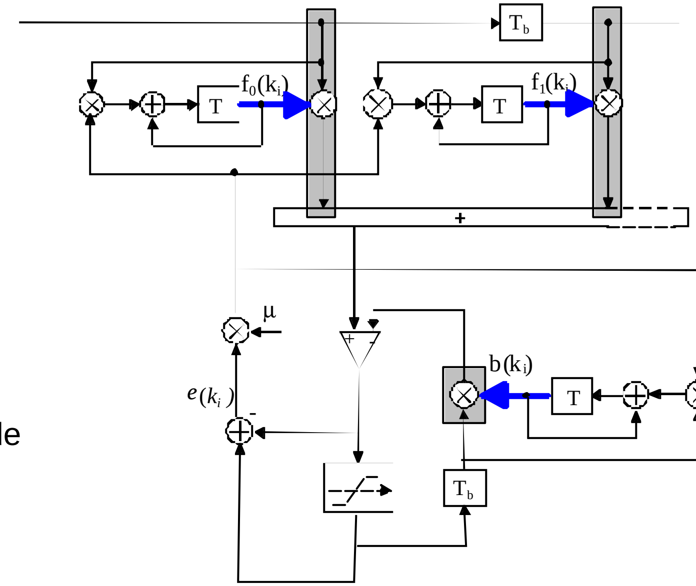
Acquisition behavior of LMS algorithm

Monte-Carlo simulation

DGD=$0.8T_b$, $\gamma = 0.5$

equalizer: FIRDFE $\{6,2\}$, $f_3=1$, $f_i=0$, $b_{1,2}=0$





acquisition requirements:

EO>15%

BER<10^{-2}

Measurements

Equalizer:

Prototype implementation (cooperation partner) of a Fractionally spaced equalizer with 10 coefficients and LMS-based adaptive coefficient setting

Performance evaluation

Experiments were carried out in the lab at the chair for communications in Kiel (10Gb/s)

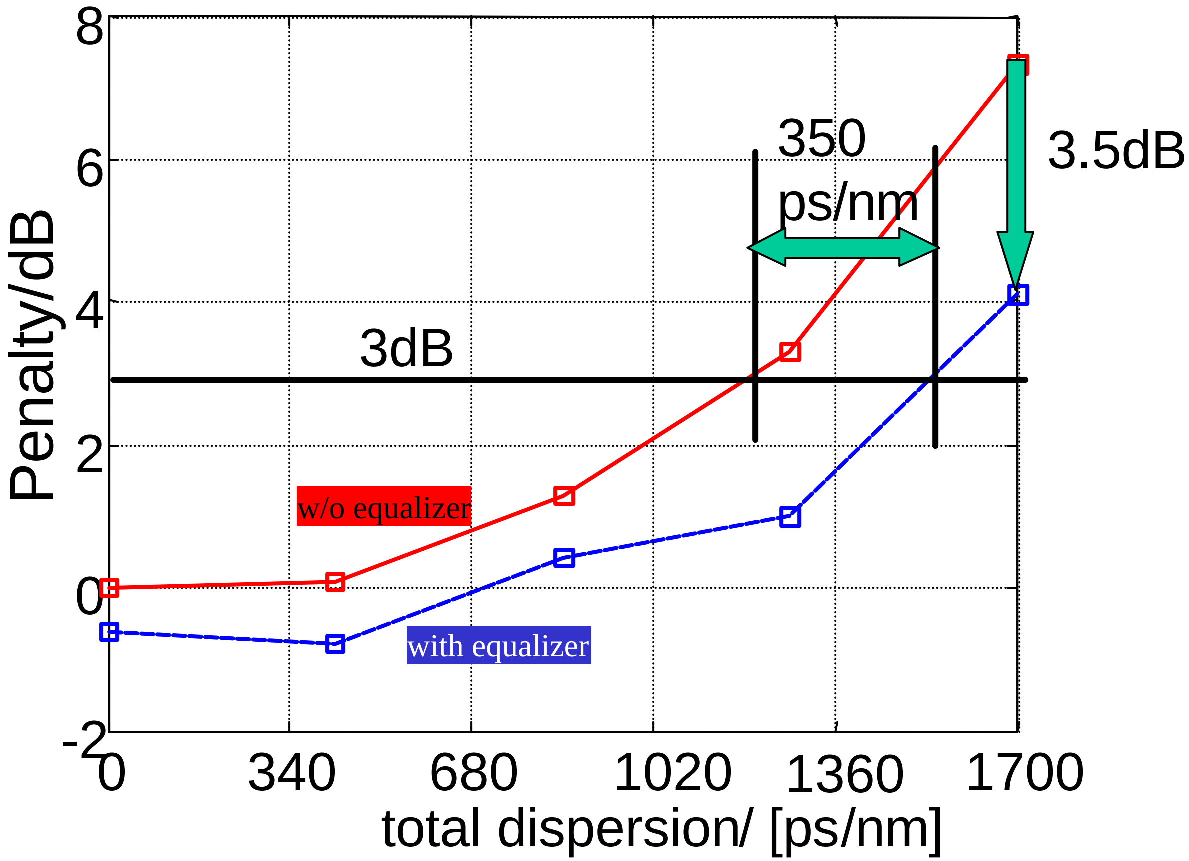
Measurement Results for GVD

uncompensated link with linear fiber behavior and D=17ps/nm/km

Decreased sensitivity against residual dispersion @3dB PP: 350ps/nm

improvement in maximal transmission distance @ 3dB PP: 20km

Power Penalty reduction @L=100km: 3.5dB

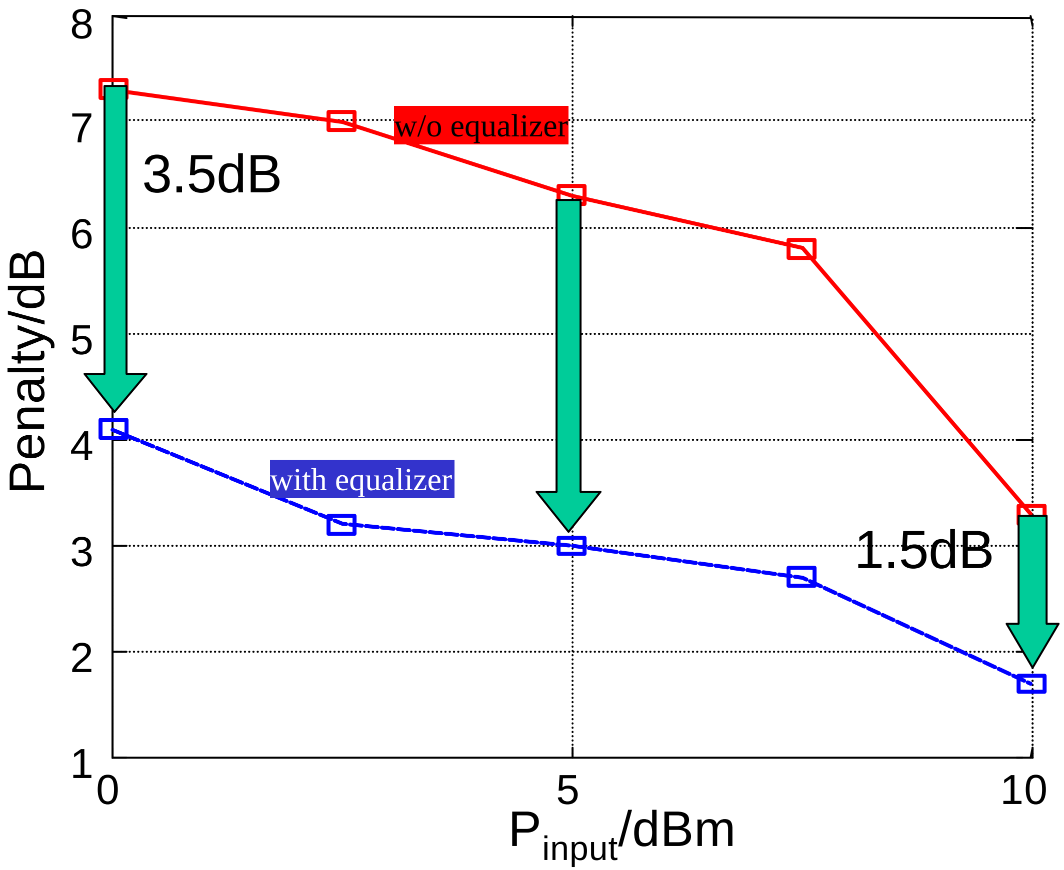


Measurement Results for SPM

uncompensated link with high optical input power, 1700ps/nm (L=100km)

SPM effect causes additional nonlinear signal components within electrical receiving signal

Power Penalty reduction decreases from 3.5dB w/o SPM to 1.5dB with an considerable impact of SPM



Simulation Results for PMD

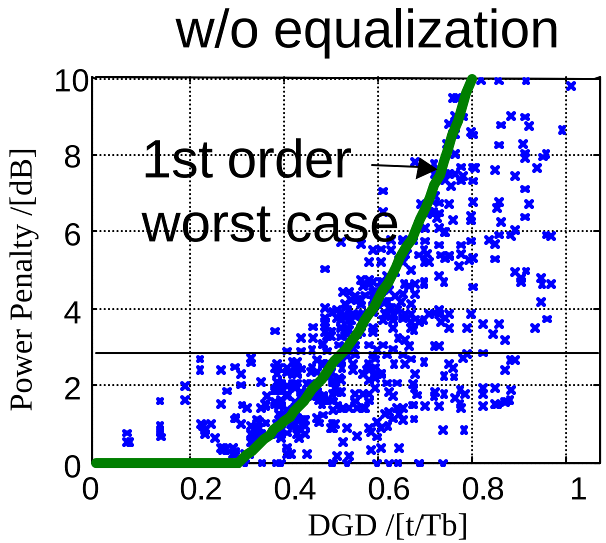
PMD parameter:

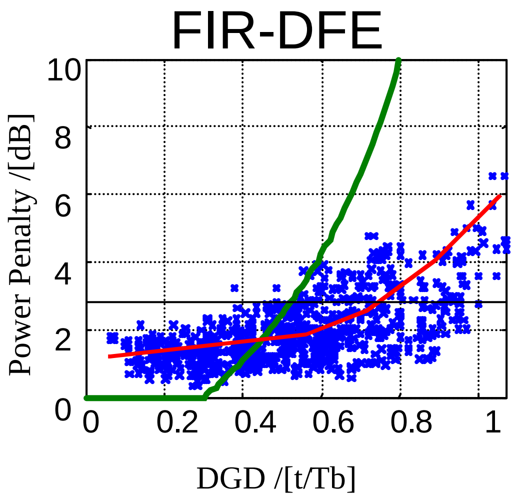
mean DGD value = PMD = $0.5T_b$

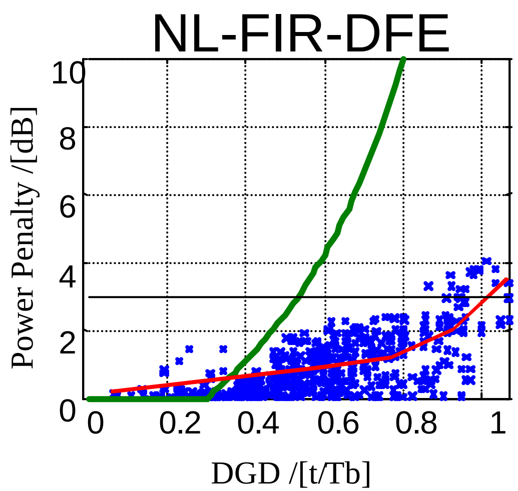
wave plates =100

assuming an outage probability of 10^{-5} (5min/year) a tolerable DGD of $\Delta\tau$ corresponds to PMD= $\Delta\tau$ /3.2

DGD		PMD
$0.3T_b$	⇨	**$0.1T_b$** w/o
$0.6T_b$	⇨	$0.2T_b$ FIR-DFE
$0.9T_b$	⇨	**$0.3T_b$** NL-FIR-DFE







Summary of Results and Conclusions

PMD

$PMD/\sqrt{L}$	Maximum transmission distance in km at 10Gb/s			Maximum transmission distance in km at 40Gb/s		
	w/o equalization	FFIRDFE	NLFIRDFE	w/o equalization	FFIRDFE	NLFIRDFE
0.1	10000	40000	90000	625	2500	5625
2	25	100	225	1.56	6.25	14

GVD/SPM

P_{input} in dBm	Dispersion tolerance in ps/nm at 10Gb/s			Dispersion tolerance in ps/nm at 40Gb/s		
	w/o equalization	FFIRDFE	NLFIRDFE	w/o equalization	FFIRDFE	NLFIRDFE
0	1200	1800	1800	80	140	150
10	1000	1750	1500	-	-	-

Project summary so far

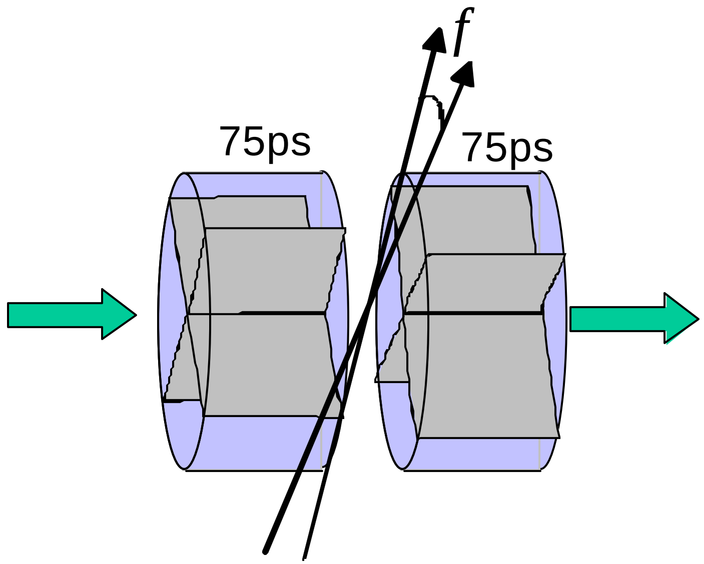
- A Volterra-Theory model has been developed which enables a theoretical performance analysis of electronic equalizer in optical transmission systems
- A complete performance evaluation including adaptation algorithm properties were performed on a simulation basis at 10Gb/s and 40Gb/s for GVD, SPM and PMD
- Experimental Performance evaluation at 10Gb/s in cooperation with an industry partner

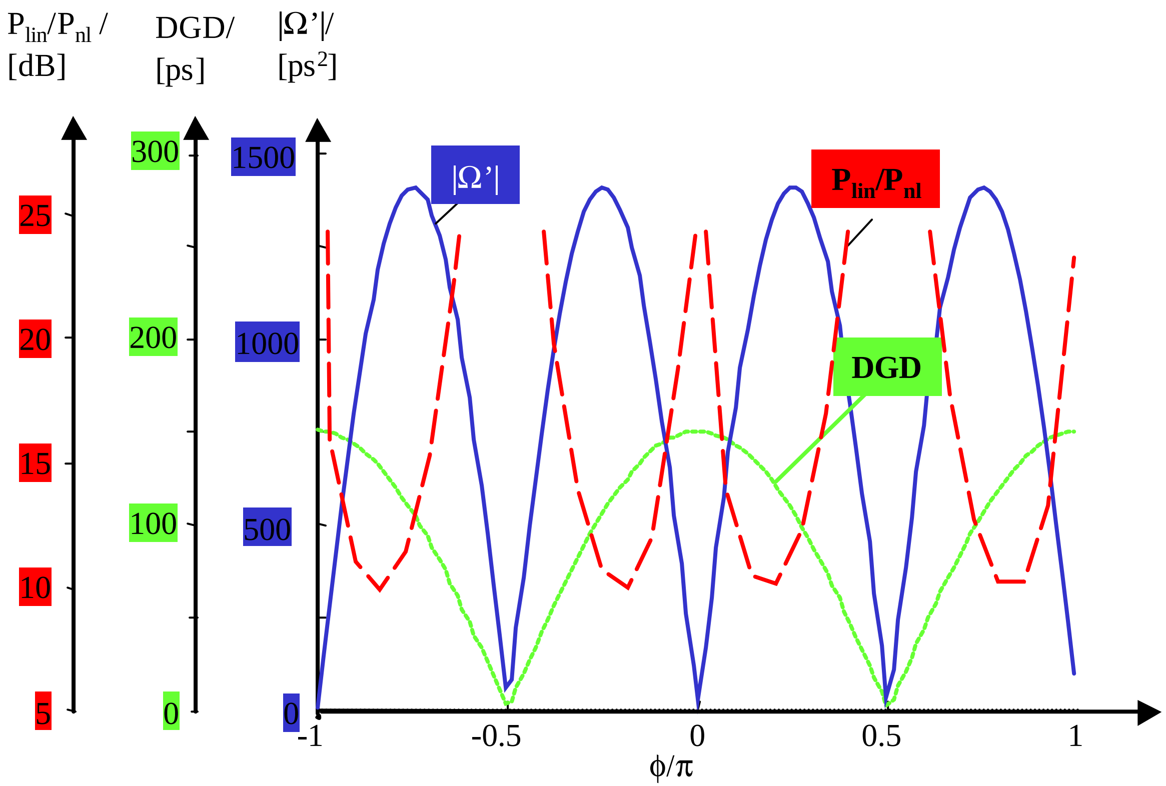
Thanks to the

Deutsche Forschungsgemeinschaft

for supporting this work!!

Nonlinear Signal components within the electrical receiving signal for a 2 section PMD-model





Nonlinear components vanish if 2nd order coefficient vanishes.

That is either if

fast/slow axis coincide with **fast/slow** axis or
fast/slow axis coincide with **slow/fast** axis