

# POF System Simulation- Showing the real Potential of POF links

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# Requirements on the simulation tool

## Overview

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System

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PSpice

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Simulink

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Improvements

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DMT Simulation

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DFE Simulation

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- Mathematical and experimental based models for different fibers
- Using of different photo diodes and optical sources
- Changing of physical parameters in simulation by user
- Optimization of equalization techniques
- Simulation of different modulation types (e.g. PAM, DMT)
- Simulation of eye diagrams, constellations and BER calculation
- Integration of fiber models with circuit simulation (e.g. PSpice)

# Fast SI-POF system overview

**what's possible over 100 m standard POF**  
*(step index, 1 mm, class A4a.2)*

- **Siemens 2006:** 1.00 Gbit/s over 100 m  
SI-POF with DMT and FEC
- **POF-AC 2007:** 1.39 Gbit/s over 100 m  
SI-POF with passive equalizer
- **Siemens 2007:** 1.51 Gbit/s over 100 m  
SI-POF with DMT and FEC
- **TU Munich 2008:** 2.00 Gbit/s over 100 m  
SI-POF with FFE/DFE ( $\text{BER} < 10^{-3}$ )
- ....

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## Overview

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# Our system (POF-AC 2007)

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Overview**System**

PSpice

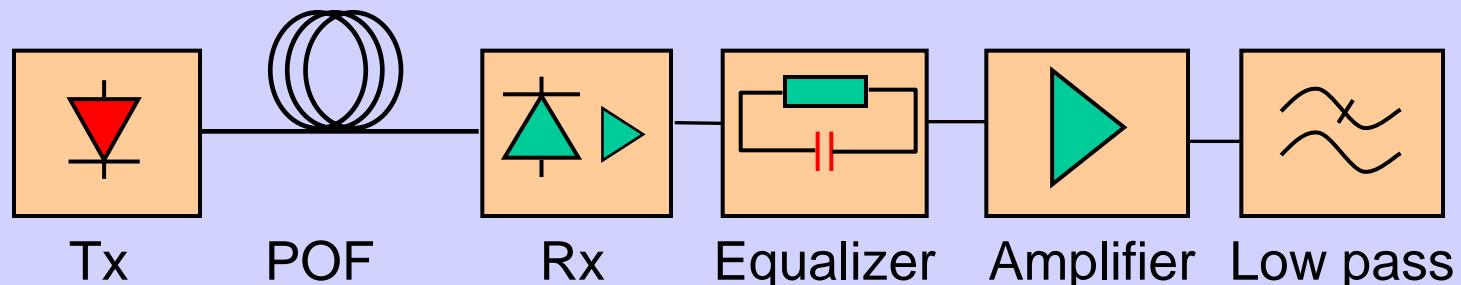
Simulink

Improvements

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DFE Simulation

## 1.39 Gbit/s over 100 m SI-POF



- Mitsubishi GH-4001 100 m
- $P_{\text{opt}}$  +6.7 dBm
- S5052 800  $\mu\text{m}$
- Received opt. Power -2.94 dBm
- TIA Rx -15 dBm@650 nm
- Passive Equalizer

# Fiber modelling

Overview

**System**

PSpice

Simulink

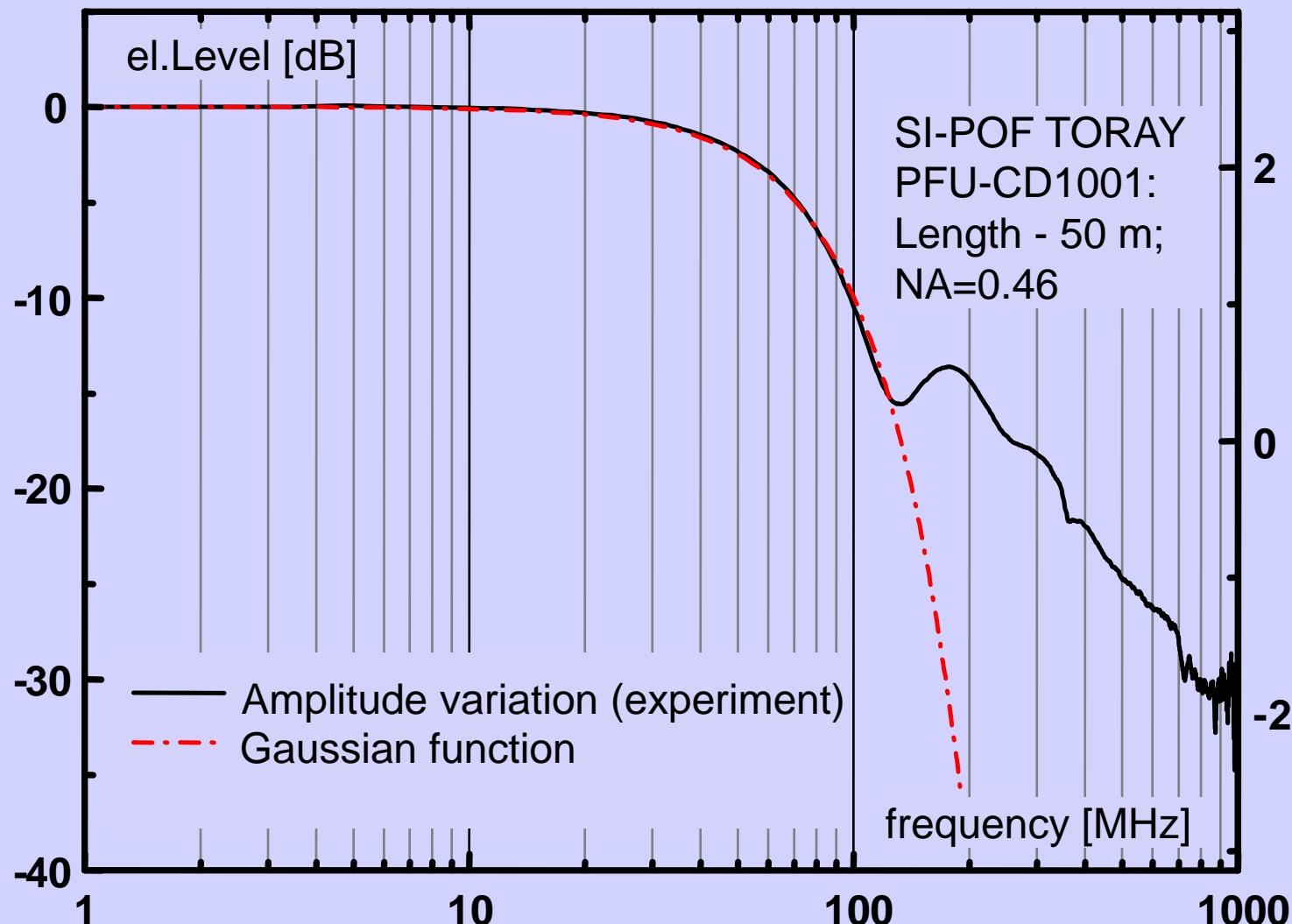
Improvements

DMT Simulation

DFE Simulation

Juri Vinogradov  
24 March 2009

[www.pofac.de](http://www.pofac.de)



# The optimized equalizer (hand made)

Overview

**System**

PSpice

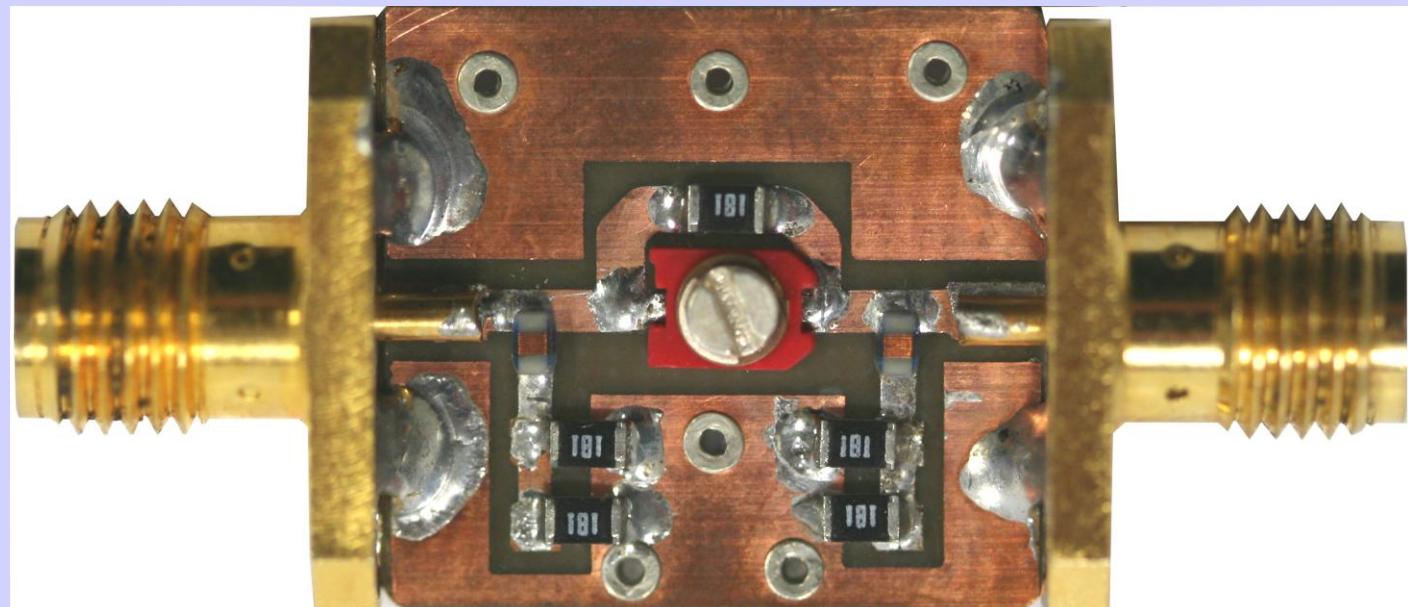
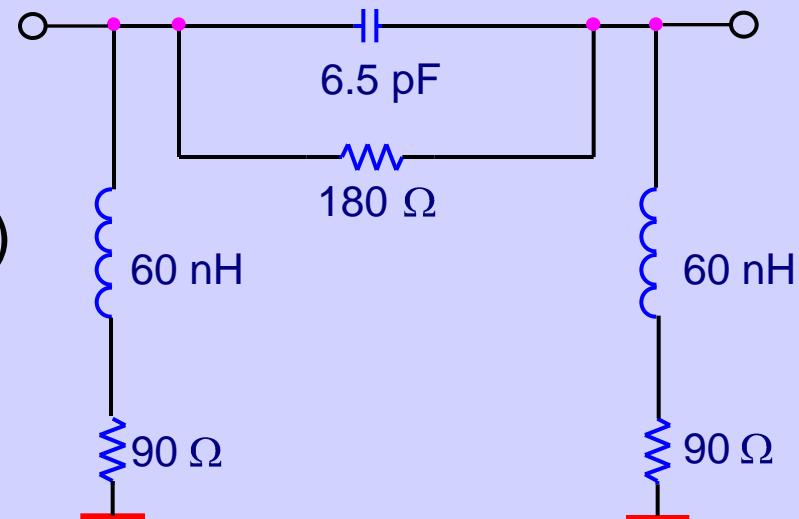
Simulink

Improvements

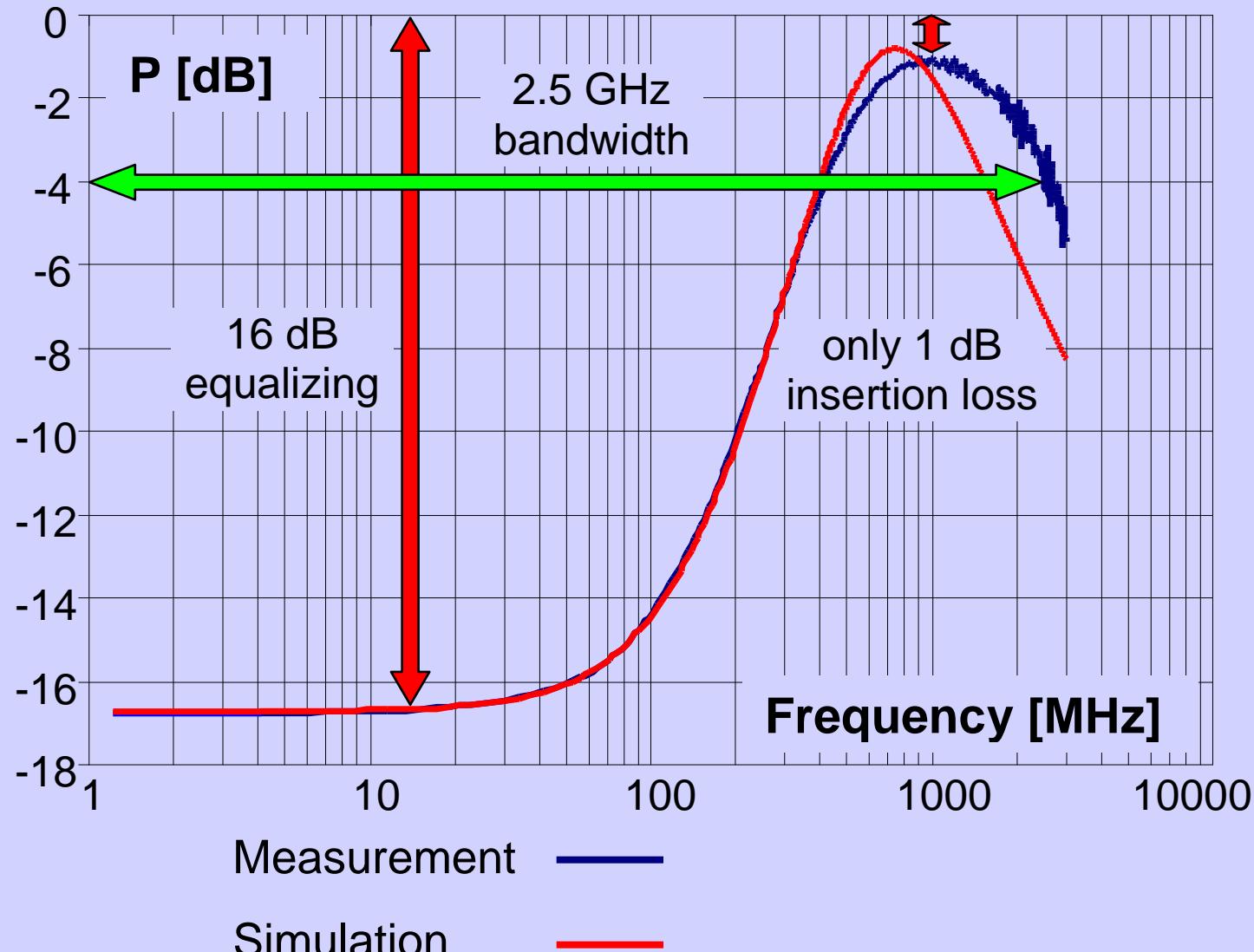
DMT Simulation

DFE Simulation

- 5 SMD resistors
- (size 0805)
- 1 SMD capacitor (var)
- $f_{3\text{dB}} : 35 - 176 \text{ MHz}$



# Measurement and simulation

[Overview](#)[\*\*System\*\*](#)[PSpice](#)[Simulink](#)[Improvements](#)[DMT Simulation](#)[DFE Simulation](#)

# Simulation Tools

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Overview

System

**PSpice**

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Simulink

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DMT Simulation

DFE Simulation

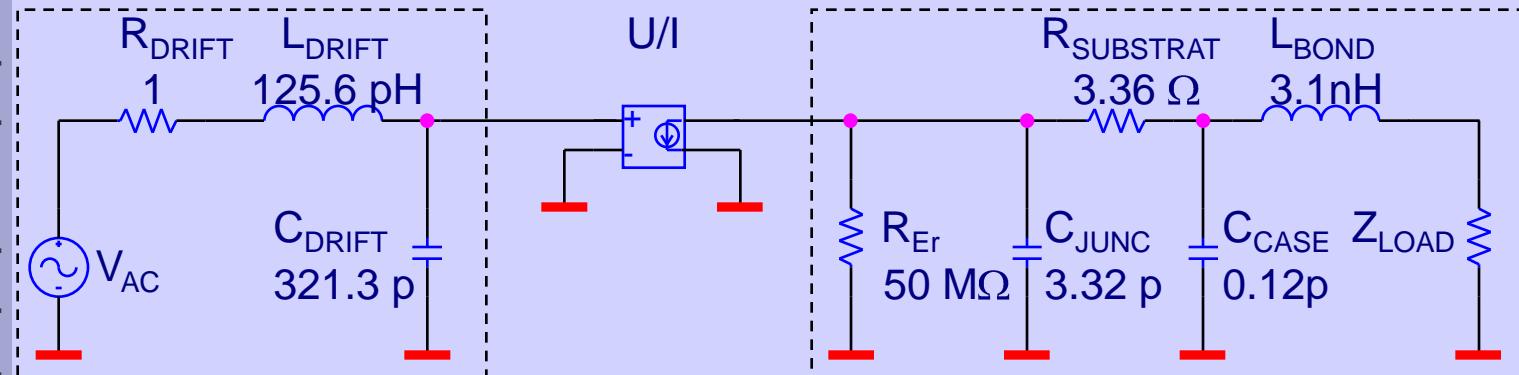
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## PSpice

- Direct design for electrical circuits
- Lot of electrical components available (FET, OpAmp)
- Analog Behavioral Modeling (ABM)
- PRBS Sources, eye diagram, BER, I/Q must be implemented

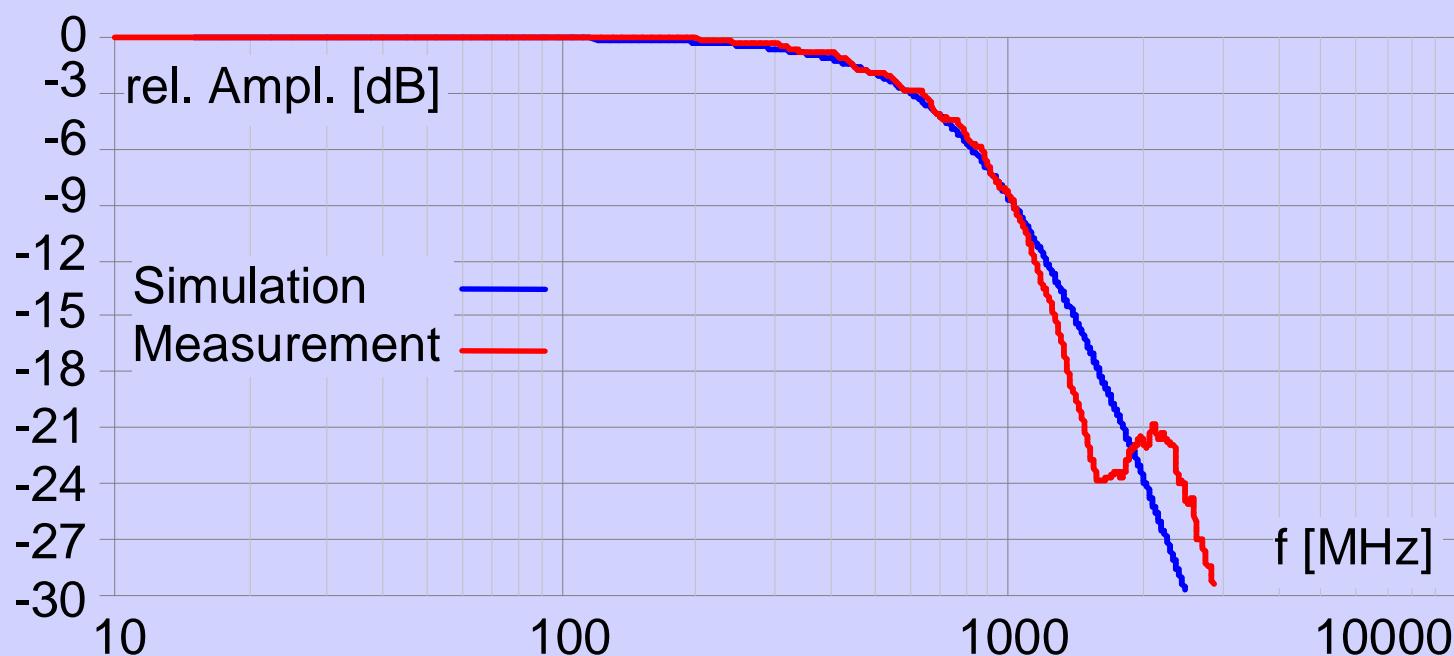
## Simulink

- Instrument for Eye, BER or I/Q Measurements → RF toolbox
- Better handling with mathematical expression and experimental data (e.g. Phase response)



Electrons/Holes drift circuit

Parasitic circuit



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Overview

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System**PSpice**

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Simulink

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Improvements

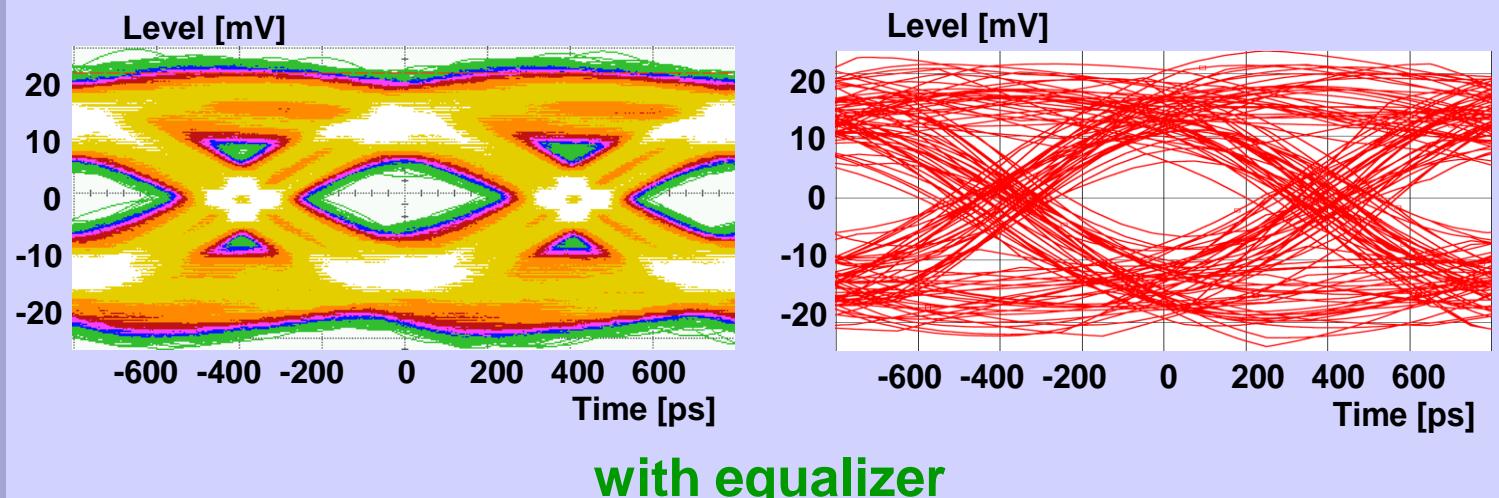
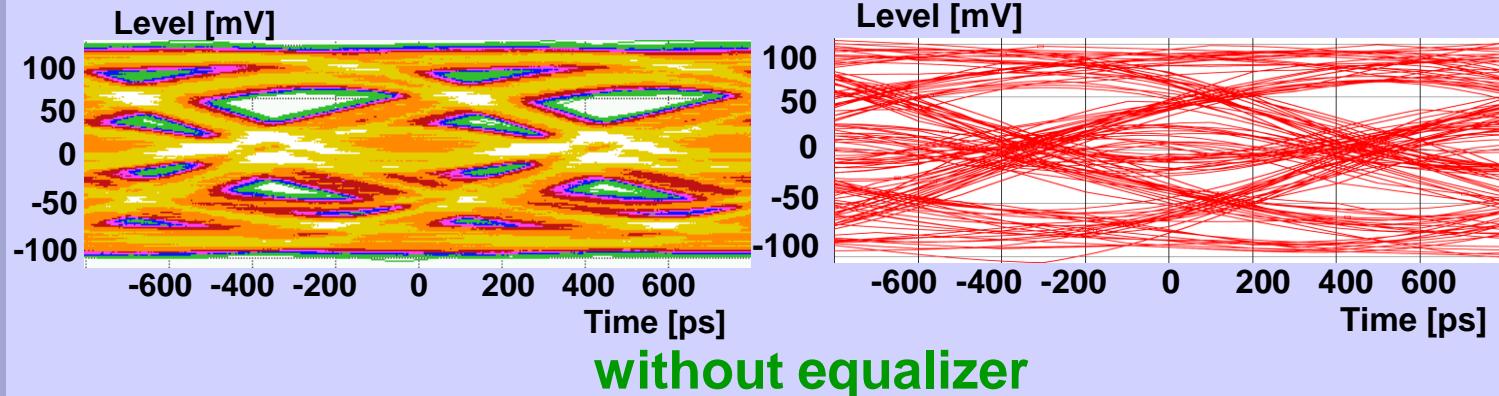
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DMT Simulation

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DFE Simulation

## Measurement and PSpice Simulation



# Intermediate remarks

- PSpice is suitable for the simulation of POF transmission systems
- POF transfer function can be implemented as frequency, amplitude and phase (network analyzer measurement data S21)
- Implementation of Phase response is difficult → Non-Causality
- PRBS signal, Eye diagram, BER calculation are not included in PSpice (made by self or application notes)

**new approach: Simulink !**

# Simulation with Simulink®

Overview

System

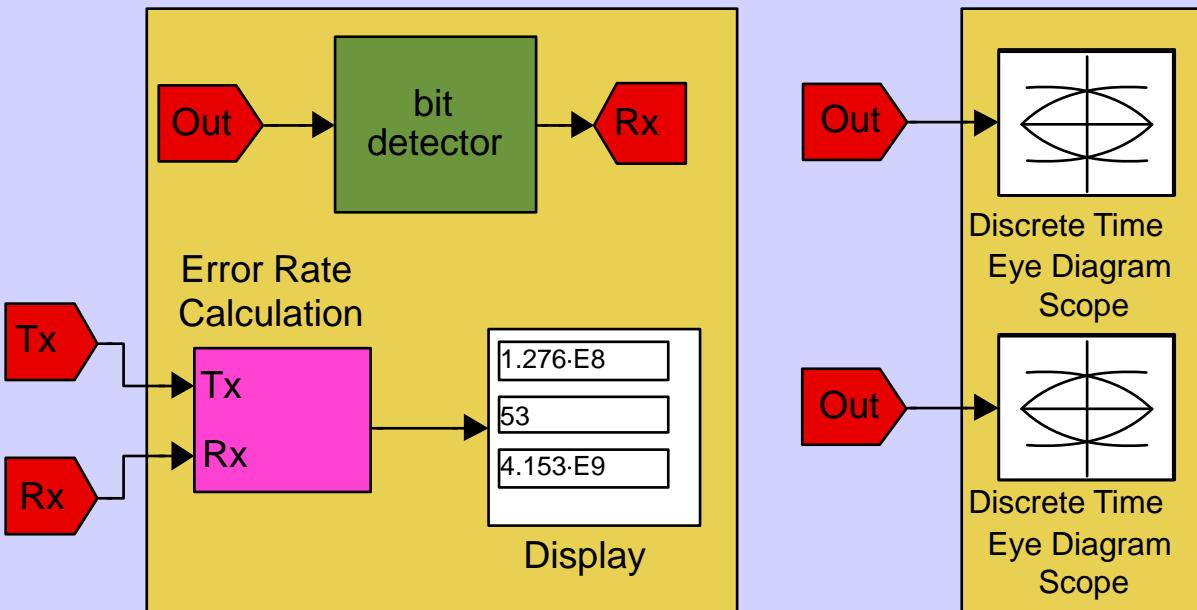
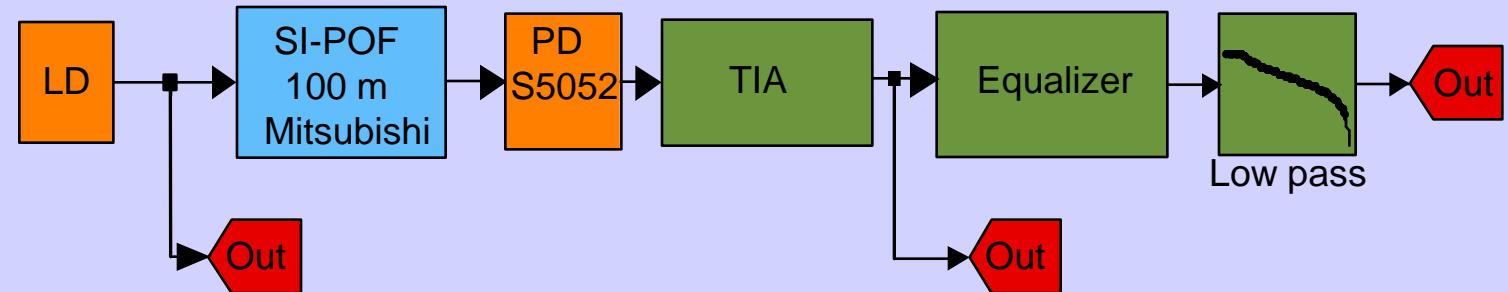
PSpice

**Simulink**

Improvements

DMT Simulation

DFE Simulation



# Photo diode dialog box (example)

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Overview

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System

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PSpice

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**Simulink**

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Improvements

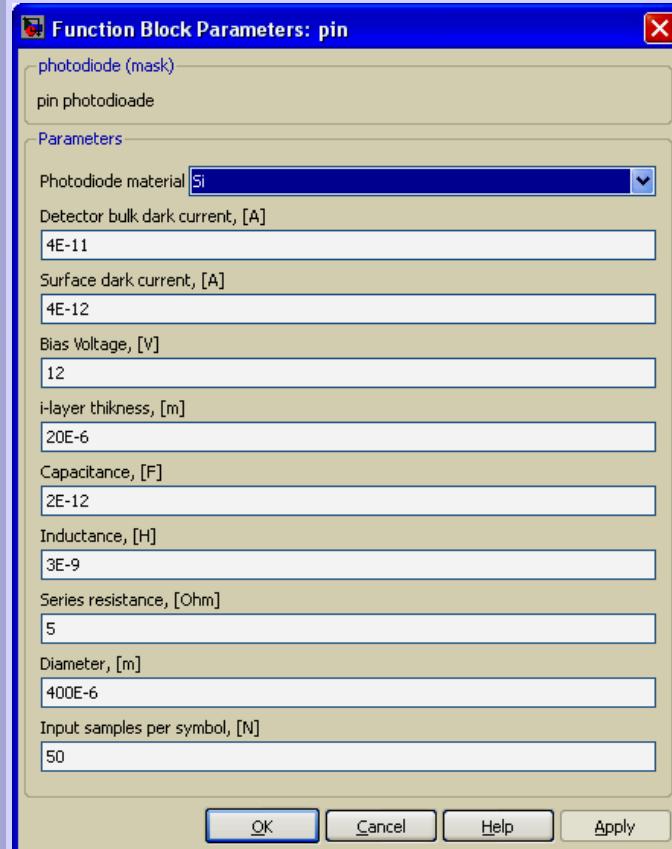
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DMT Simulation

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DFE Simulation

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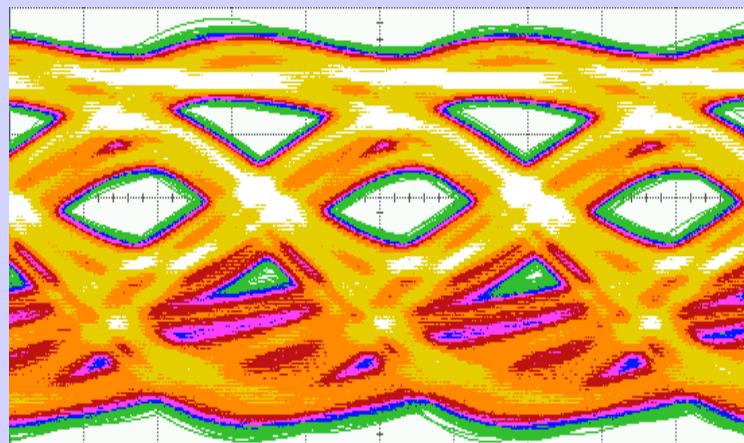


## Parameters:

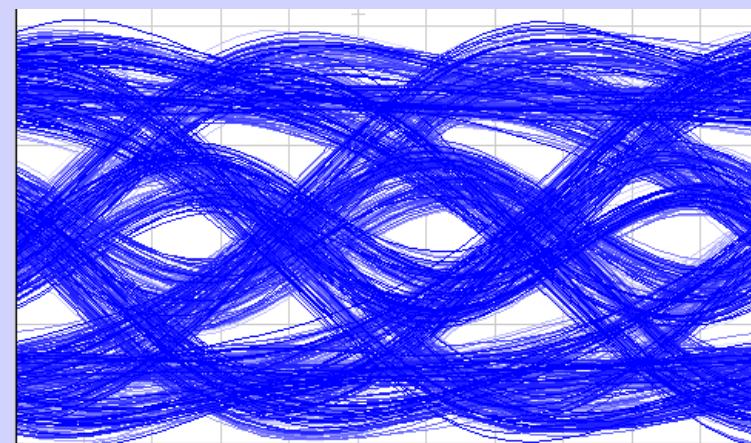
- Photodiode material
- Bulk dark current [A]
- Surface dark current [A]
- Bias voltage [V]
- i-layer thickness [m]
- Capacitance [F]
- Inductance [H]
- Series resistance [Ohm]
- Diameter [m]
- Samples per symbol [N]

# 1.39 Gbit/s over 100 m Mitsubishi SI-POF 14

## Measured and simulated eye diagram



Time [ns]



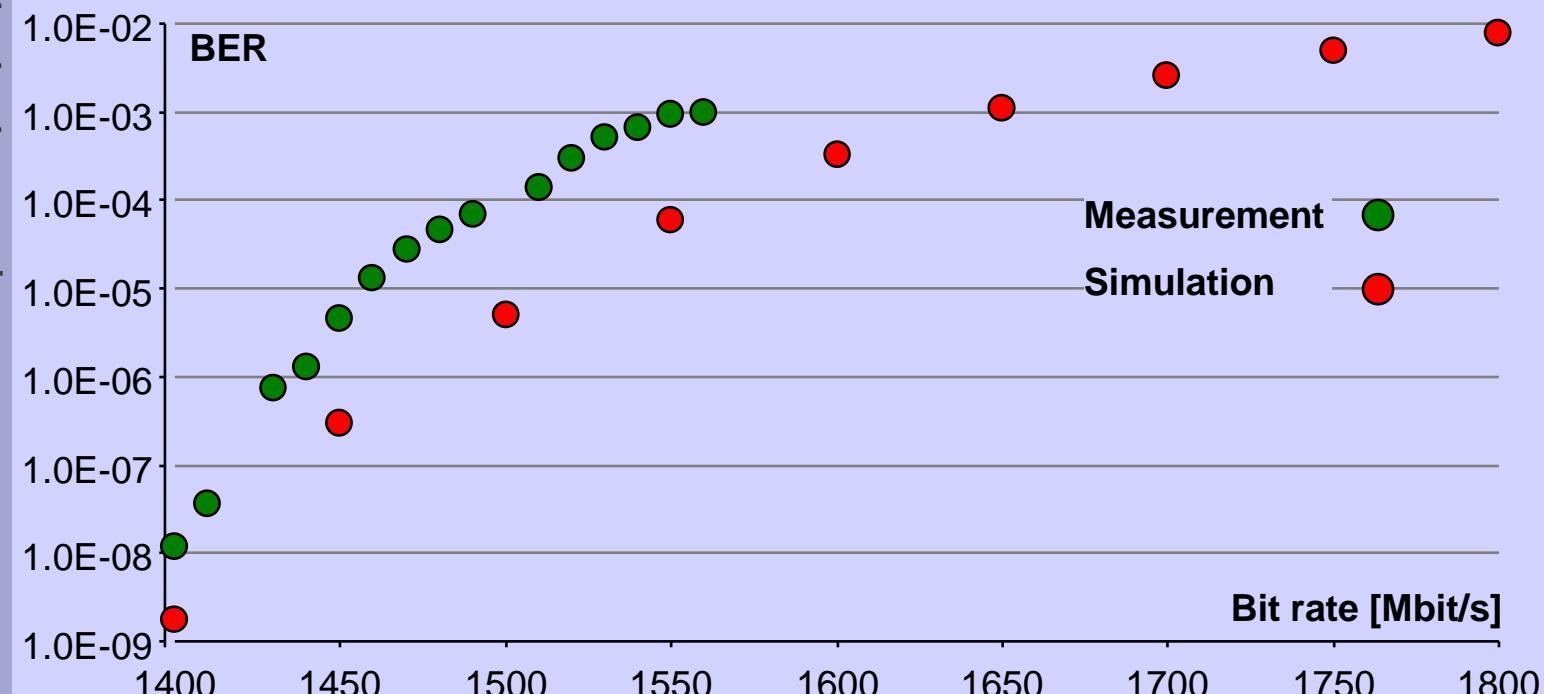
Time [ns]

650 nm LD, +6.5 dBm  
received power: -11 dBm  
 $\text{BER} \approx 10^{-9}$

# 1.39 Gbit/s over 100 m Mitsubishi SI-POF 15

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## BER vs. bit rate



Juri Vinogradov  
24 March 2009

# 1.39 Gbit/s over 100 m Mitsubishi SI-POF 16

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Overview

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PSpice

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**Simulink**

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Improvements

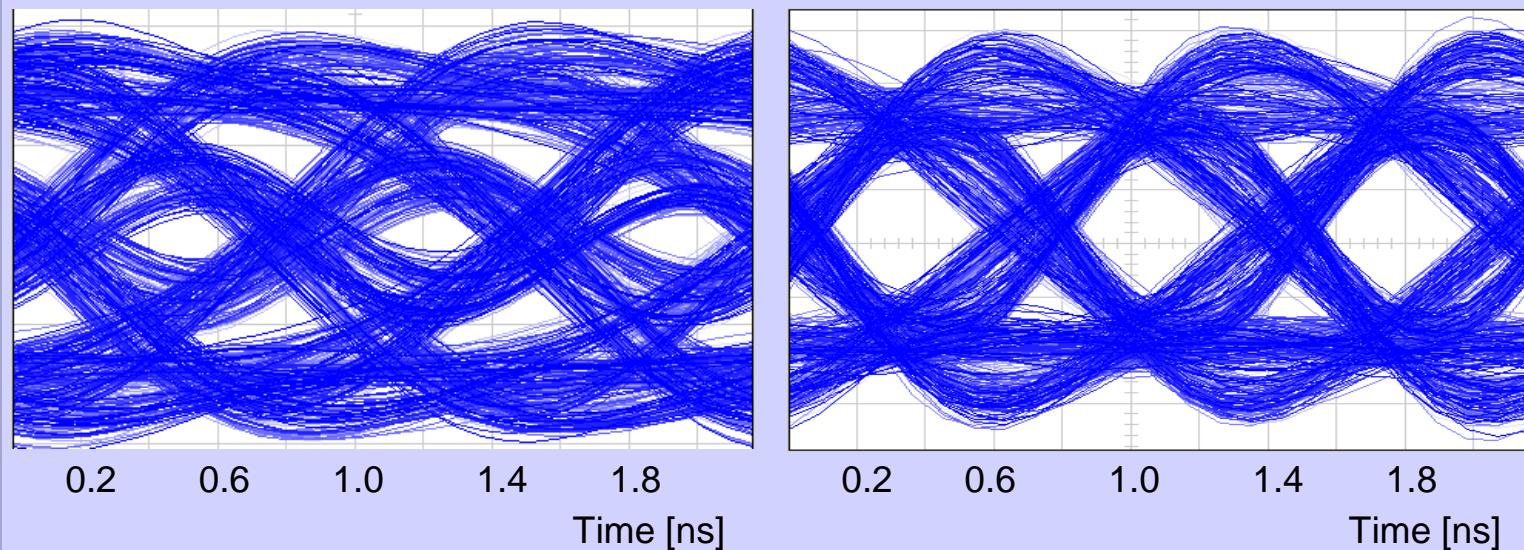
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DMT Simulation

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DFE Simulation

simulated system improvement with optimized equalizer (ideal)



- Better eye opening due to an ideal equalizer
- Penalty 4.2 dB instead 9.1 dB
- System improvement by optimized equalizer: **5.0 dB**

# Improvements

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Overview

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System

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PSpice

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Simulink

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**Improvements**

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DMT Simulation

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DFE Simulation

## Step 1: Laboratory

- optimized equalizers (e.g. as FFE)
- low noise receivers
- fully integrated optical receivers

## Step 2: real systems - is it possible with SI-POF ?

- stabilized, long life transmitter
- 50 m transmission link with connectors, bends, fiber ageing...

Overview

System

PSpice

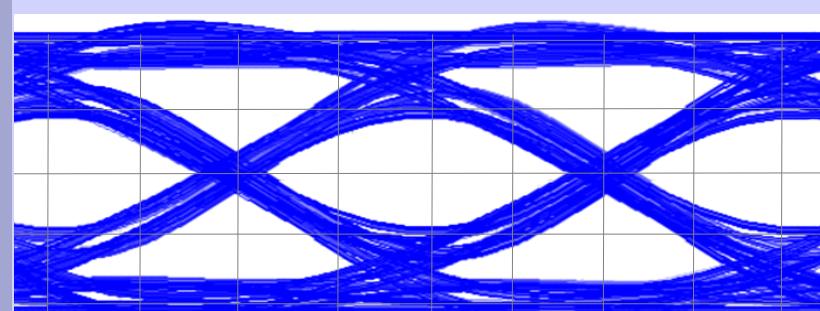
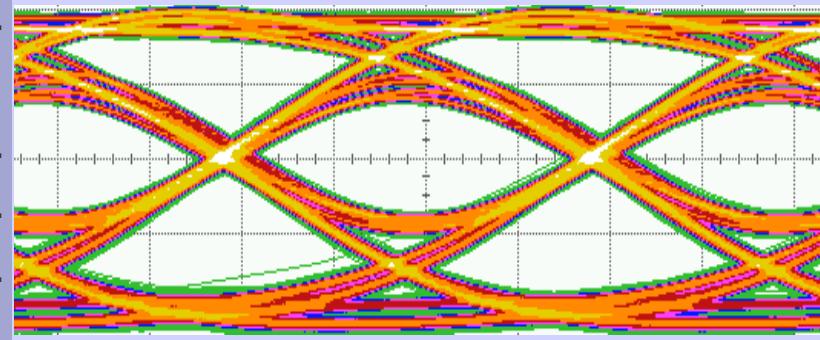
Simulink

**Improvements**

DMT Simulation

DFE Simulation

## Measured and simulated eye diagrams

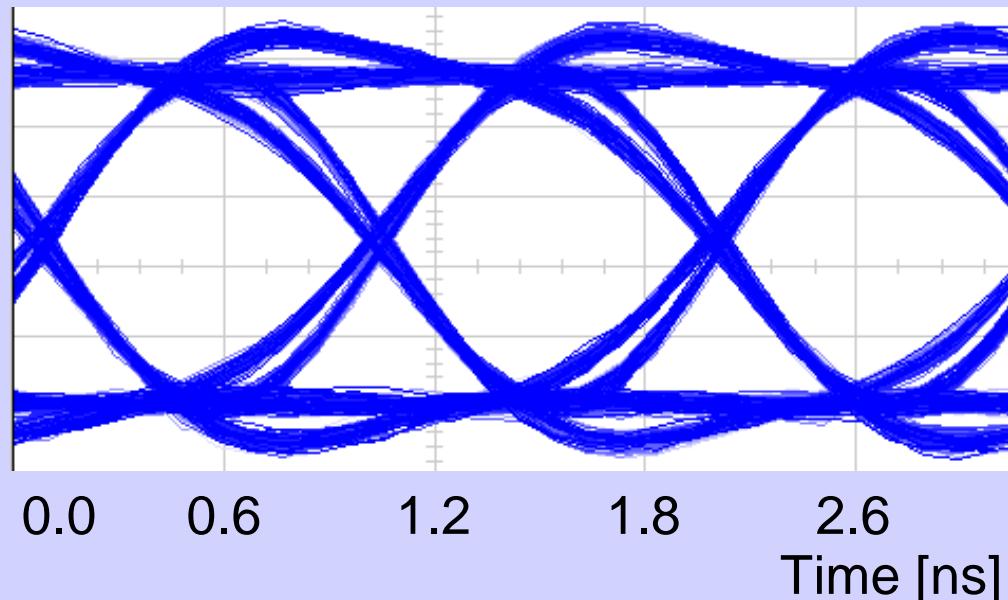


- 650 nm laser diode
- +6 dBm
- sensitivity: -16 dBm (BER  $10^{-9}$ )
- POF loss: 8 dB
- **margin: 14 dB**

# optimized 50 m system (simulation)

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- 650 nm laser diode
- 0 dBm fiber coupled power
- **optimized equalizer (ideal)**, low noise receiver
- sensitivity approx.: -18 dBm (BER  $10^{-9}$ )
- POF loss: 8 dB
- **margin: 10 dB**



# Outlook and conclusion

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Overview

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System

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PSpice

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Simulink

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**Improvements**

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DMT Simulation

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DFE Simulation

Gigabit Ethernet over 50 m SI-POF is possible (with huge power margin)

how to realize the optimized equalizer ?

- adaptive analog
- DMT
- FFE/DFE

Simulink is a possible design tool  
not only for NRZ

- DMT system (Siemens)
- DFE/FFE system (TU Munich)

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Overview

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System

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PSpice

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Simulink

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Improvements

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**DMT simulation**

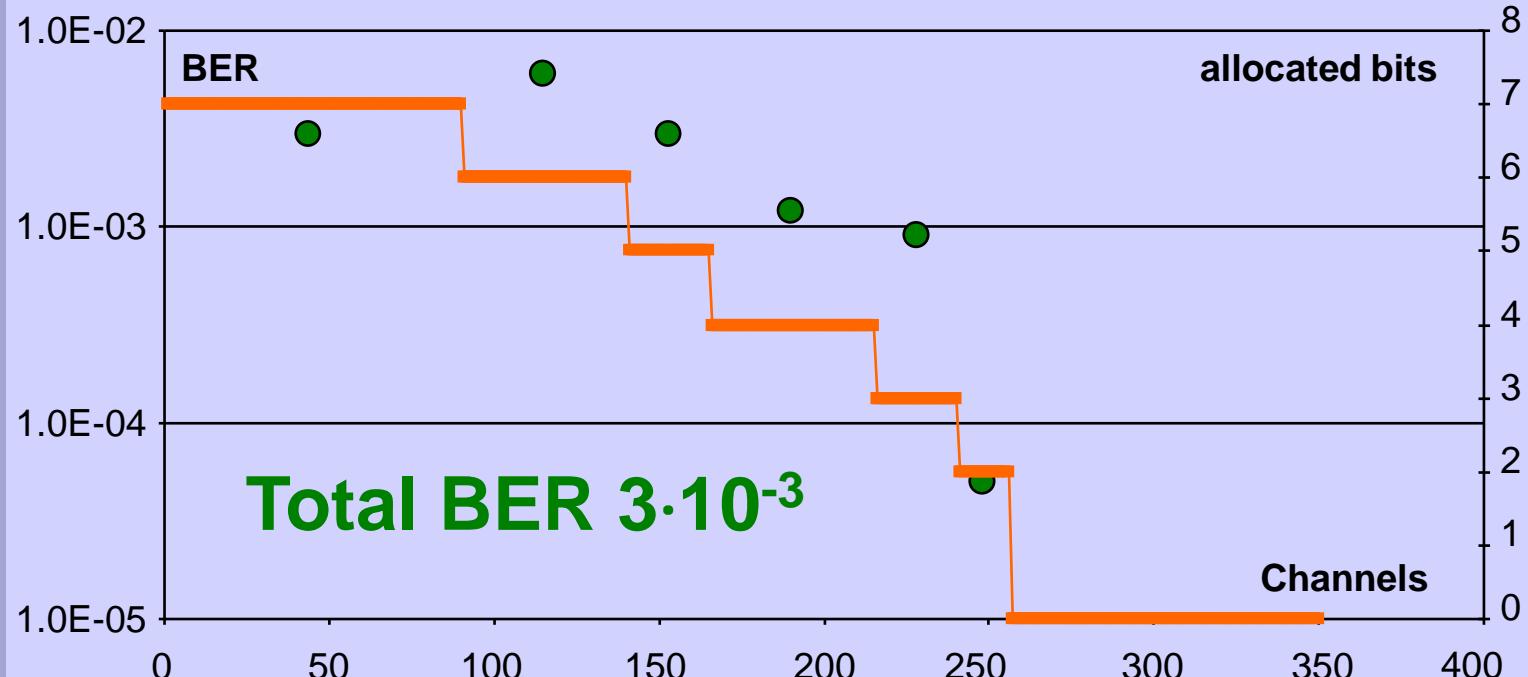
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DFE Simulation

S. C. Jeffrey Lee, F. Breyer, S. Randel, R. Gaudino, G. Bosco, A. Bluschke, M. Matthews, P. Rietzsch, R. Steglich, H. P. A. van den Boom and A. M. J. Koonen:  
**“Discrete Multitone Modulation for Maximizing Transmission Rate in Step-Index Plastic Optical Fibres”**, to be published in JLT

- 100 m SI-POF Mitsubishi
- 650 nm Laser diode
- TZA 3023 TIA; 600 µm PD
- 1.62 Gbit/s
- 256 Subchannels
- Average BER  $1 \cdot 10^{-3}$  (FEC-limit)
- Bandwidth 312.5 MHz

## Bit allocation and simulated BER



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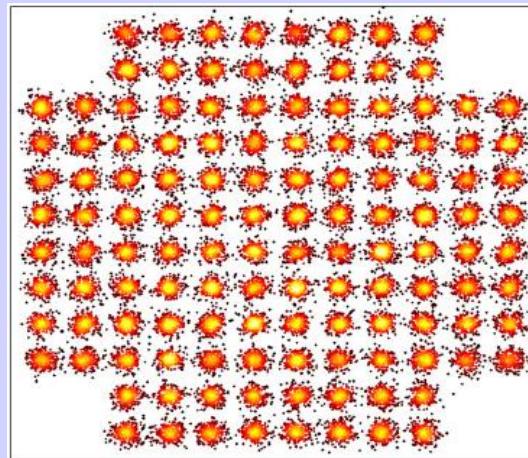
Improvements

**DMT simulation**

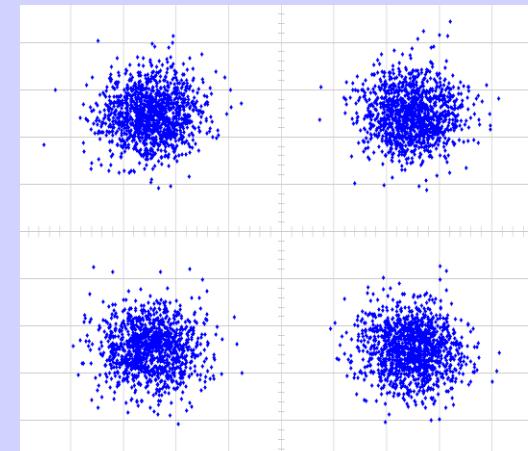
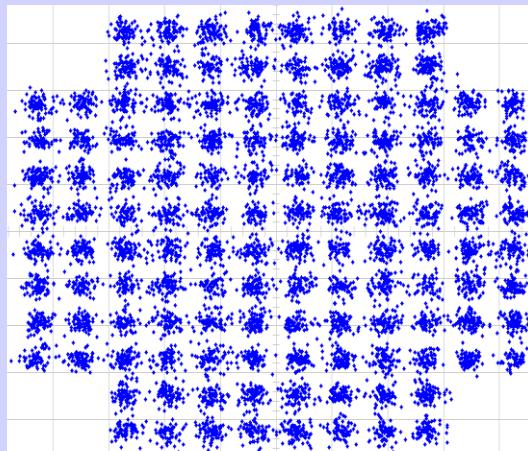
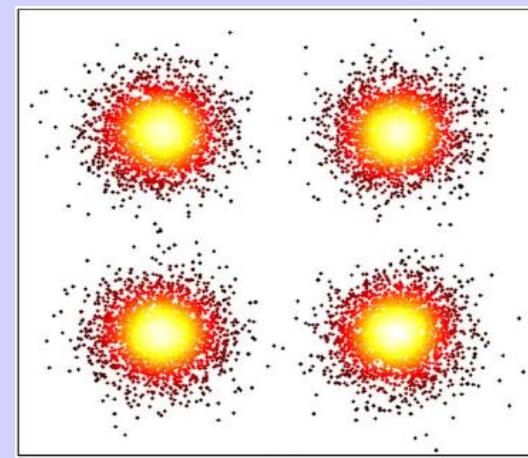
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DFE Simulation

QAM 128



QAM 4



## 2.00 Gbit/s over 100 m SI-POF with DFE 24

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Overview

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System

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PSpice

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Simulink

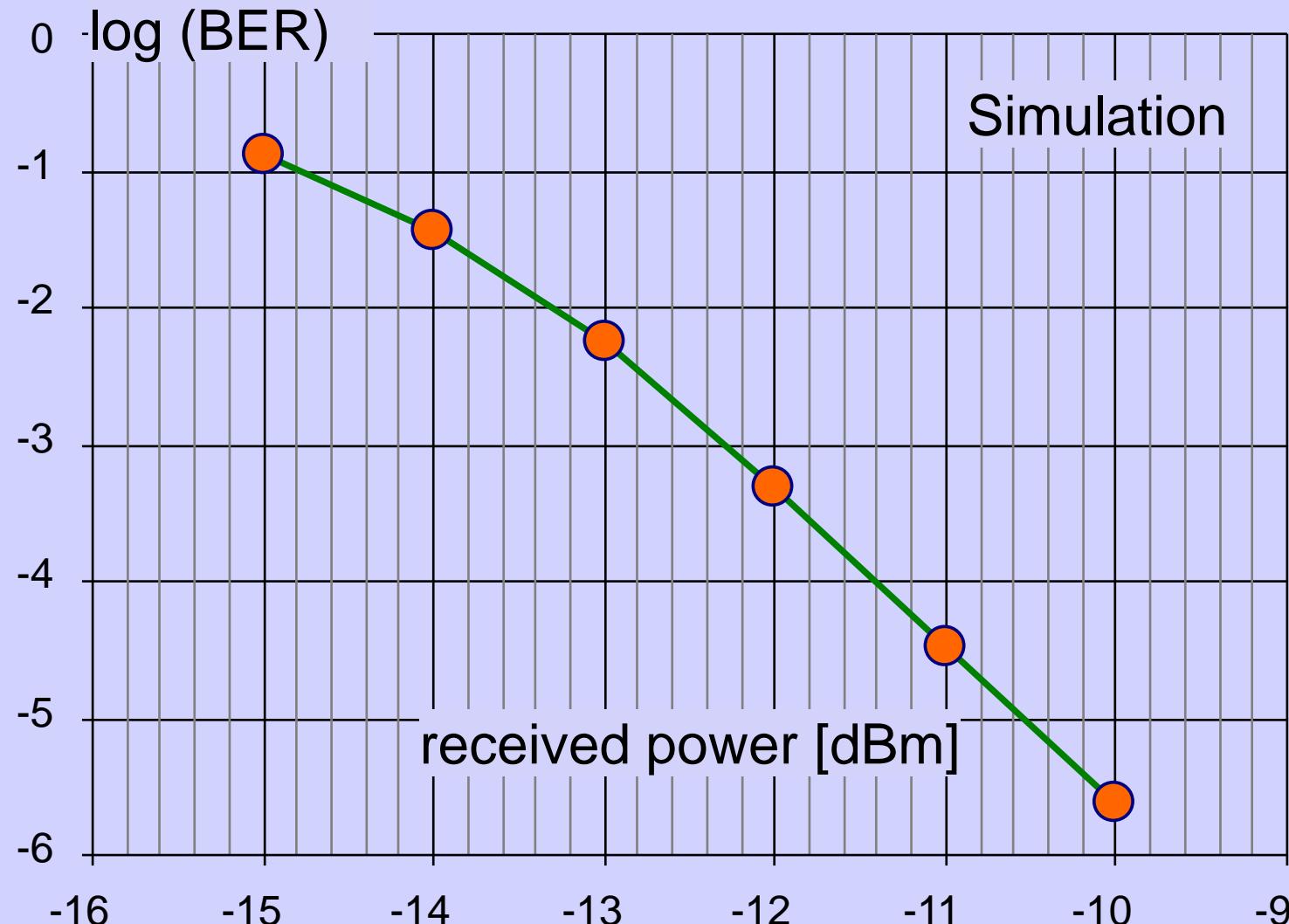
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Improvements

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DMT Simulation

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**DFE Simulation**

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Overview

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System

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PSpice

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Simulink

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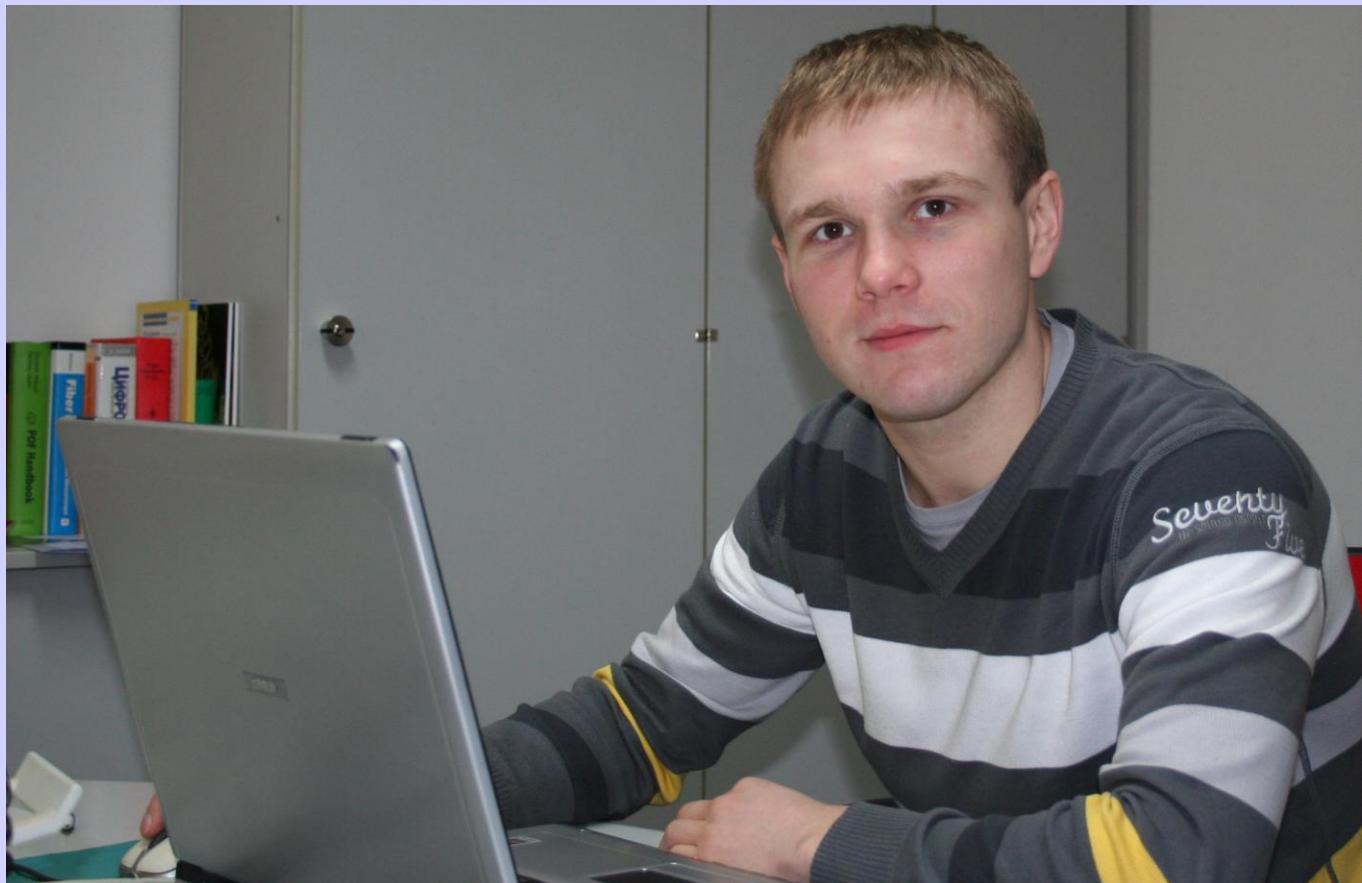
Improvements

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**DFE Simulation**



See more results on the POF conference presented by Dr. Roman Kruglov Sydney, 09.-11. Sept. 2009

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# optimized 50 m system

- Overview
- Analog equalizer
- PSpice
- Simulink
- Improvements**
- DMT Simulation

