25. meeting of the ITG-SC 5.4.1
“Polymer Optical Fibers"

Comparison of the Modulation Methods for POF Systems

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Content

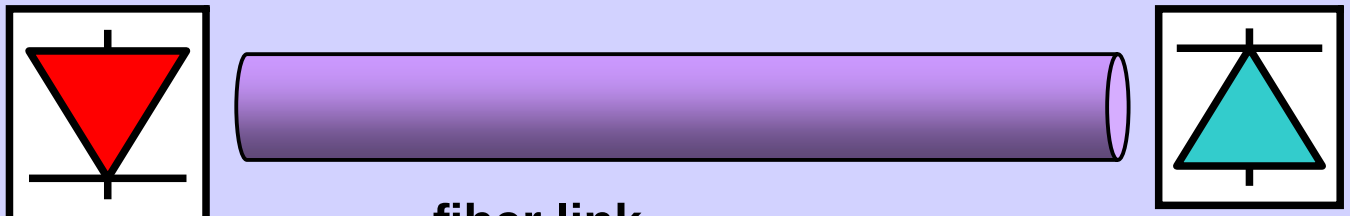
- Components in POF systems
- Definition of terms
- Bandwidth and sensitivity
- Comparison of the Modulation Methods
- Limits of real components
- Consequences and decisions

History

O. Ziemann: „Multiplexverfahren auf optischen Polymerfasern - neueste Entwick-lungen und Vergleich“, 22. FGT ITG-FG 5.4.1, München, 25.10.2006

O. Ziemann, H. Poisel, S. Randel, J. Lee: “Polymer Optical Fibers for Short, Shorter and Shortest Data Links”, OFC invited paper OWB1, 24.-28.02.2008, SanDiego

Components in POF systems



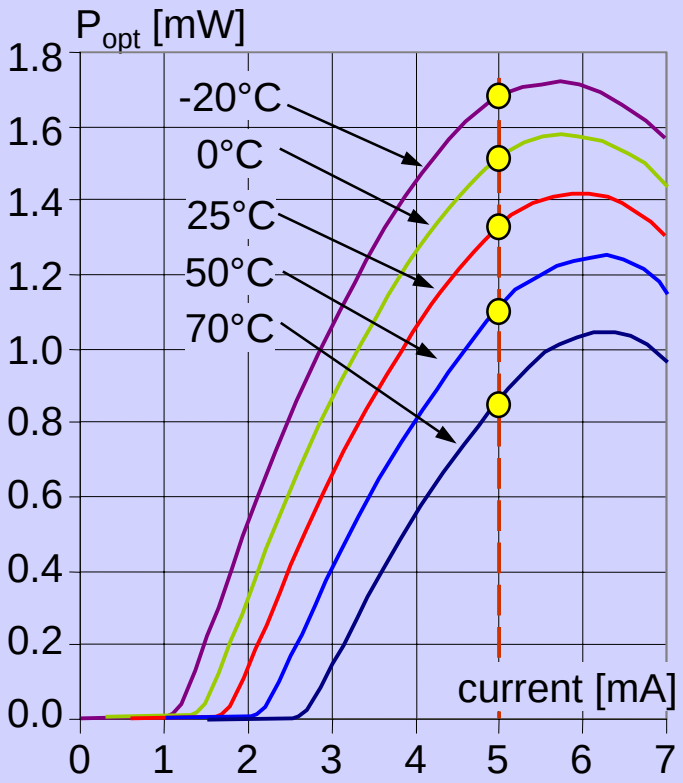
emitter diode
- bandwidth
- power
- linearity
- spectral width
- temp.-coeff.

fiber link
- bandwidth
- loss
- chrom. dispersion

photo diode
- bandwidth
- linearity
- noise
- sensitivity

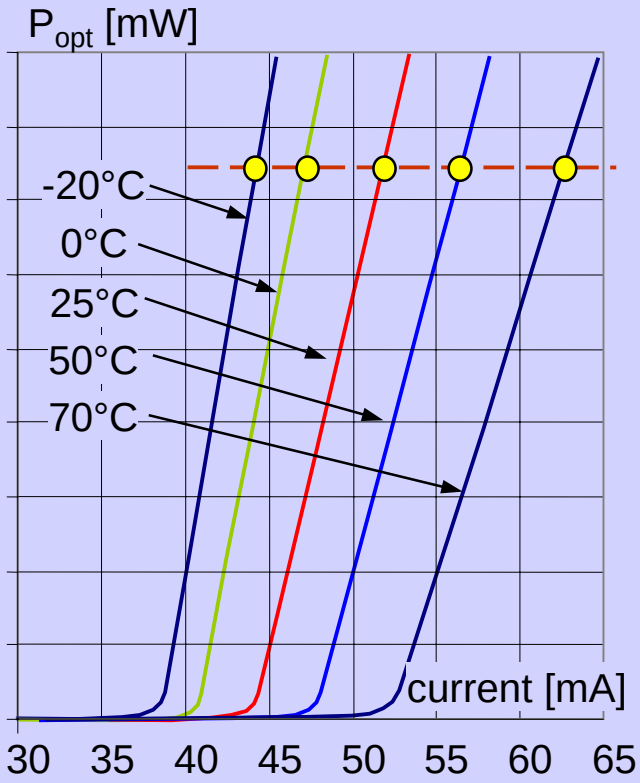
the most important transmitters

VCSEL



constant current operation

Laser



constant power operation

transmitter comparison

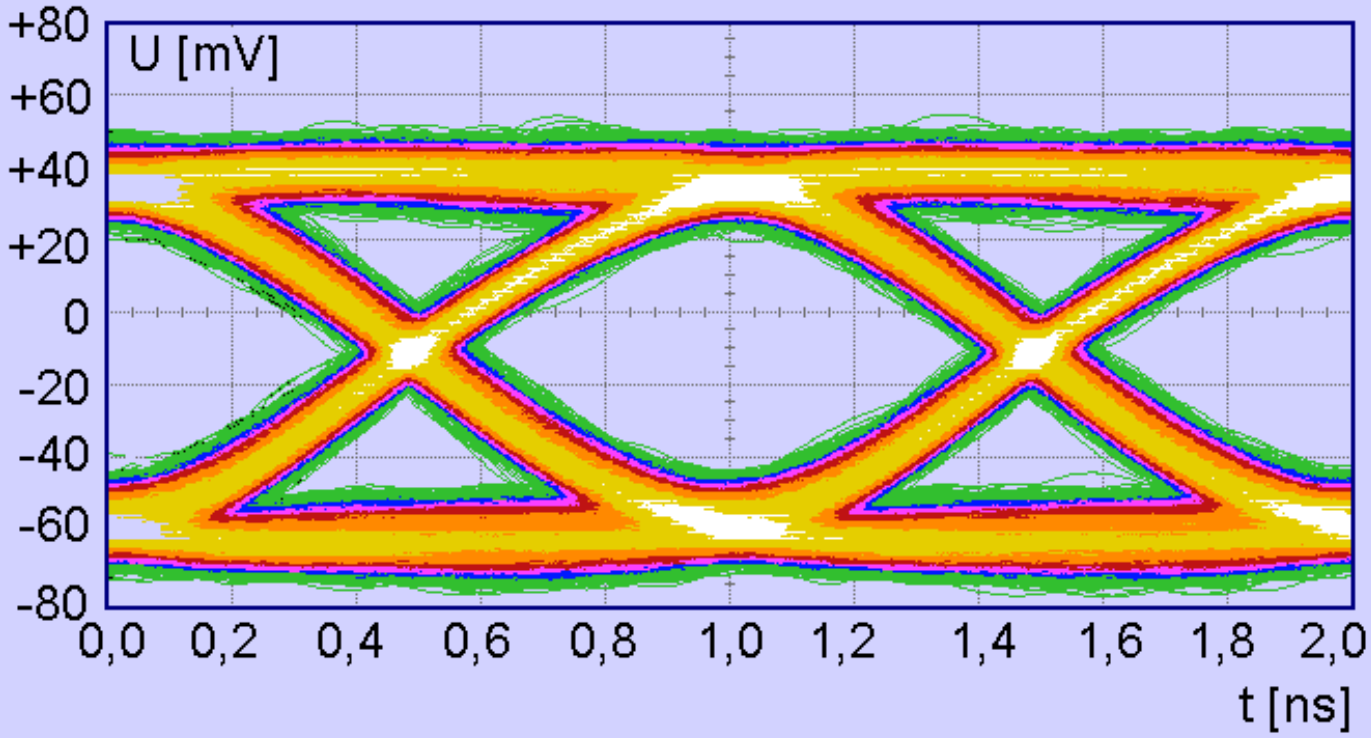
	LED	VCSEL	Laser
wavelength	all	≥660 nm	≥630 nm
typ. bandwidth	100 MHz	1000 MHz	2000 MHz
typ. power	2 mW	1 mW	5 mW
threshold	-	2 mA	25 mA
spectr. width	25 nm	4 nm	2 nm
coupling eff.	20%	80%	50%
$\Delta\lambda/\Delta T$ [nm/K]	0.08	0.04	0.12

and the winner is ....?

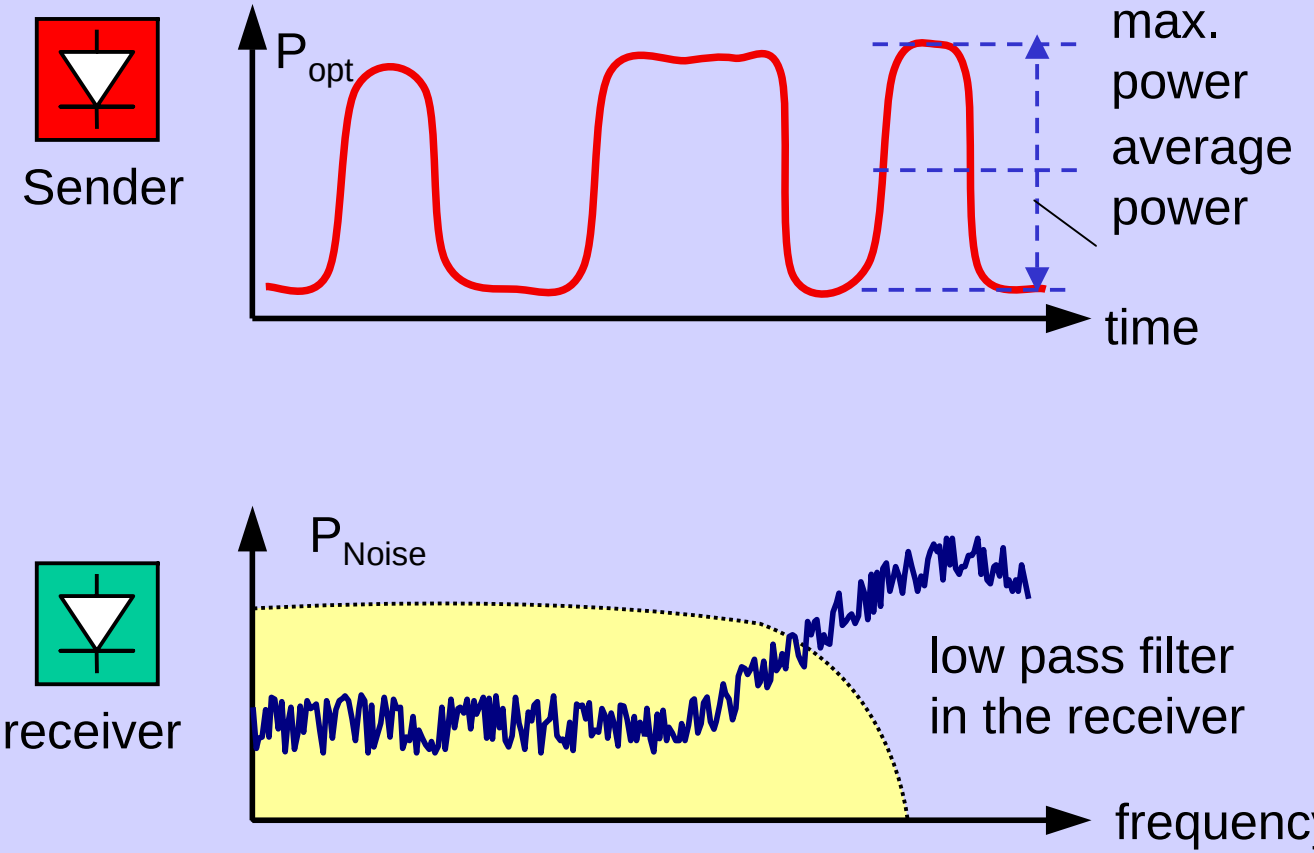
the problem of diode capacity

System data:

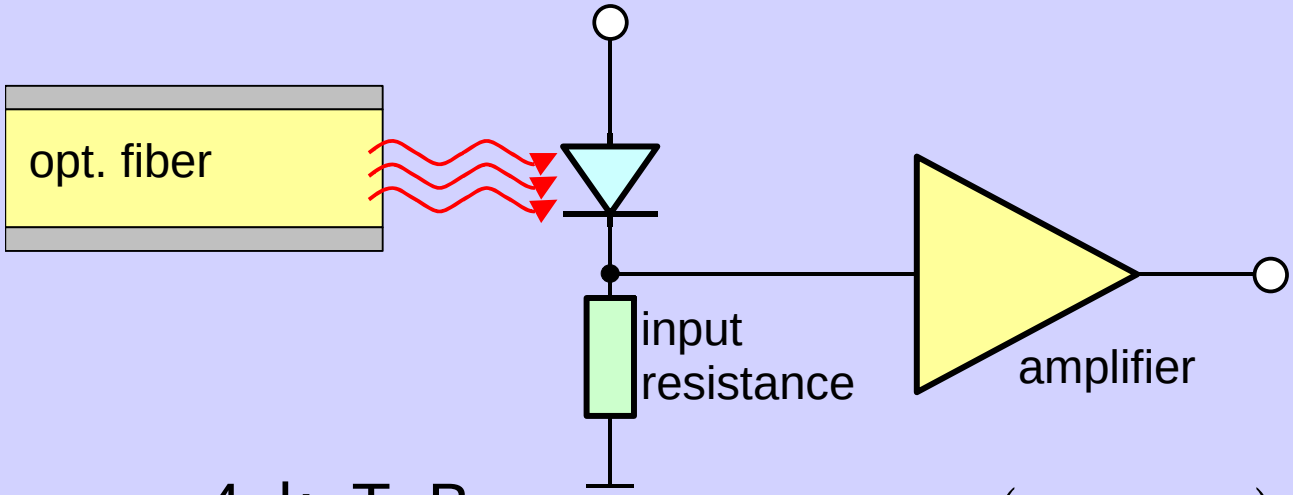
- 650 nm Laser, +6 dBm, Modulation:
- 1000 Mbit/s, NRZ, PRBS 2^7 - 1
- Si-pin-PD 1600 µm, no equalizer/noise filter
- photo diode reverse voltage: 12 V
- 50 m OM-Giga (PMMA-GI-POF, 900 µm)



influence of bit rate on the SNR



bandwidth and the RC time constant



$$\bar{i}_{th}^2 = \frac{4 \cdot k \cdot T \cdot B}{R} \qquad i_{Signal}^2 = \left(P_{opt} \cdot \Re_{PD}\right)^2$$

$$\bar{u}_{th}^2 = 4 \cdot k \cdot T \cdot B \cdot R \qquad u_{Signal}^2 = R^2 \cdot \left(P_{opt} \cdot \Re_{PD}\right)^2$$

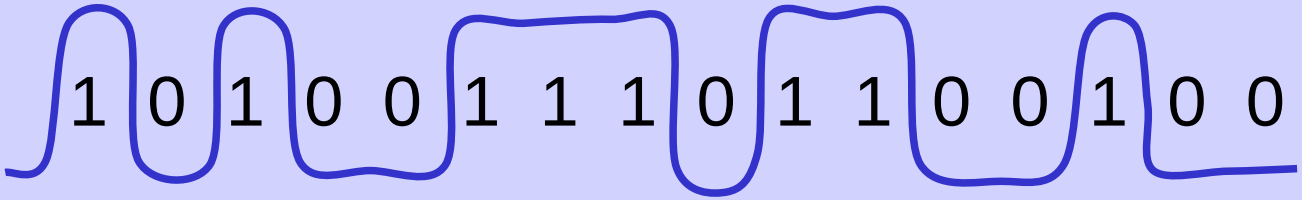
⇨ SNR is proportional to R

⇨ R is indirect proportional to the BR

higher bandwidth ⇨ higher noise density and more noise bandwidth

NRZ

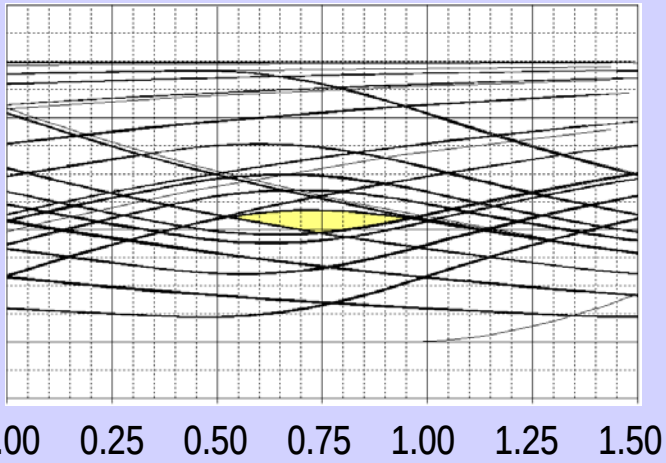
Non Return to Zero



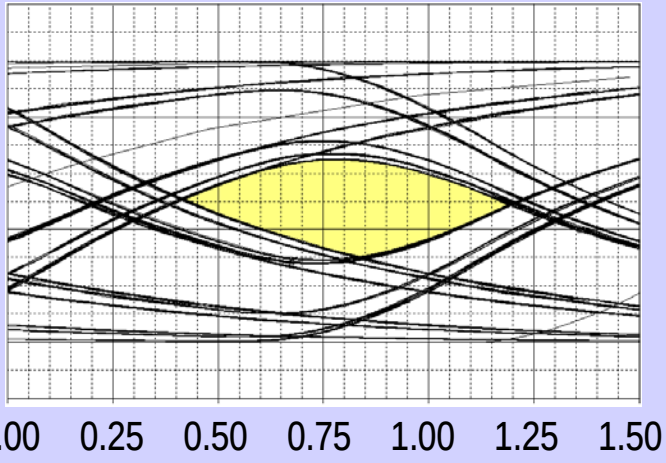
- direct modulation of the LED/LD
- linearity is less important
- to small bandwidth causes penalty
- a limiter/amplifier can be used at the receiver side
- compensation of the bandwidth using an equalizer is possible
- present best value: 1390 Mbit/s over 100 m Standard-SI-POF

Simulation of thr penalty for NRZ

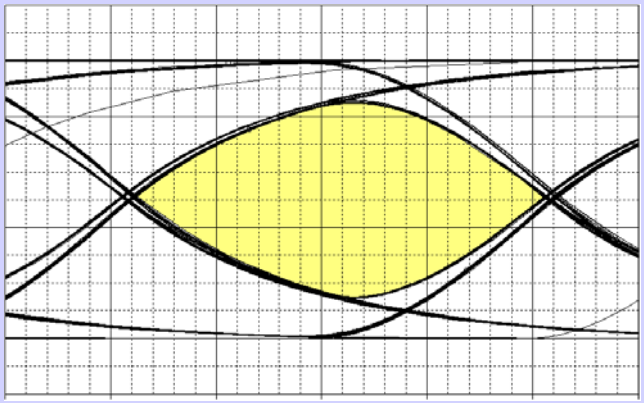
B_{Filter} = 0.1·BR



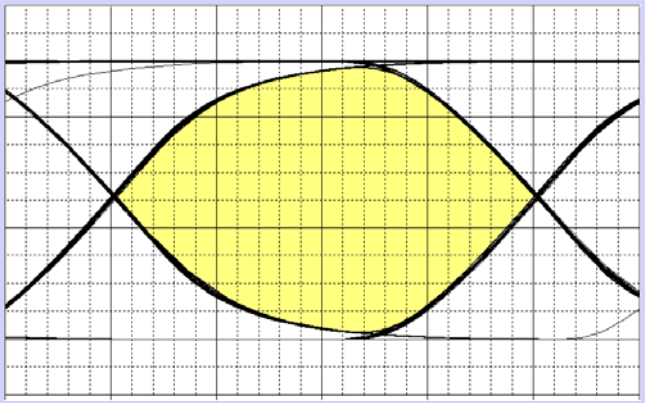
B_{Filter} = 0.2·BR



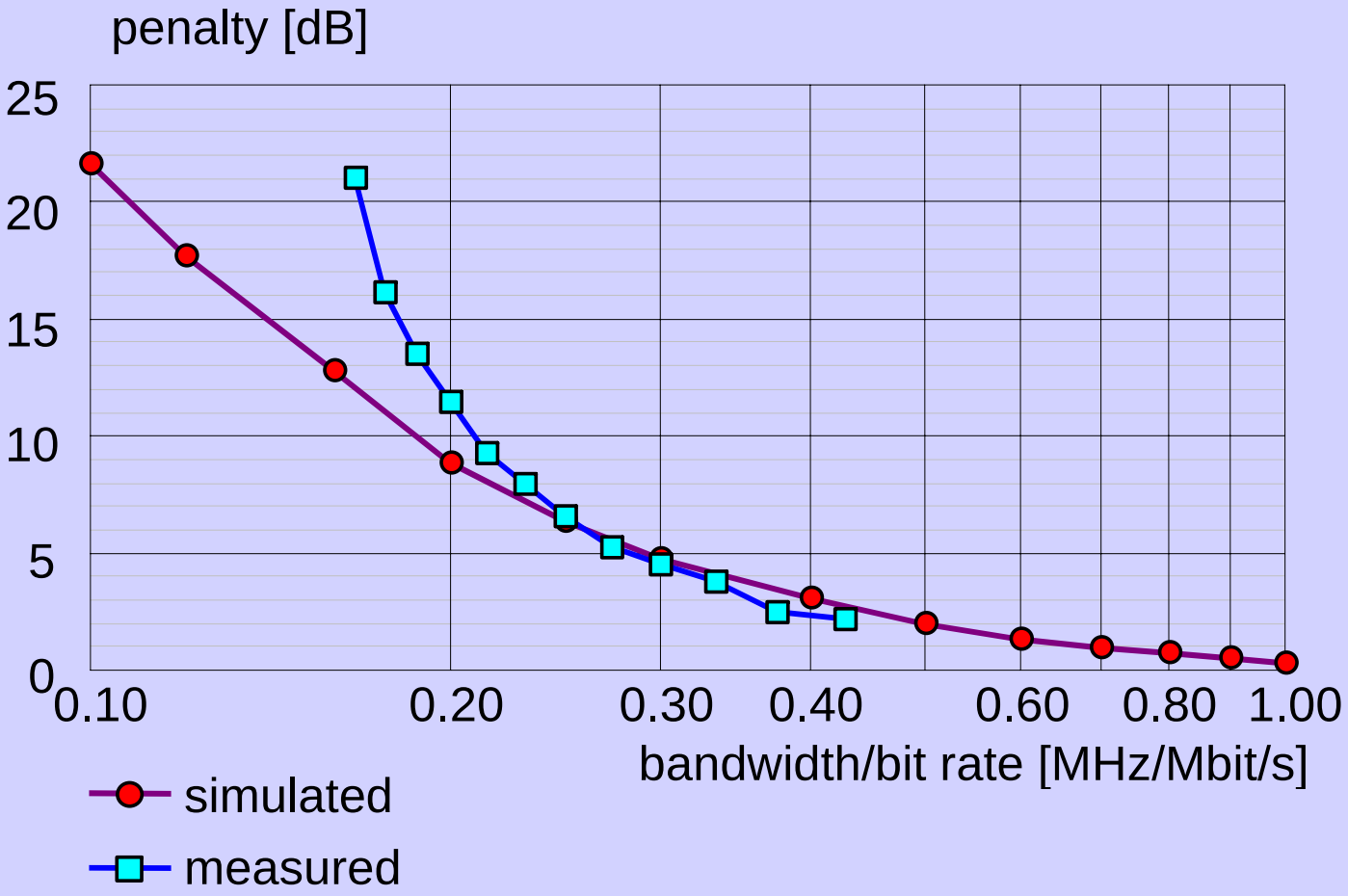
B_{Filter} = 0.4·BR



B_{Filter} = 0.9·BR

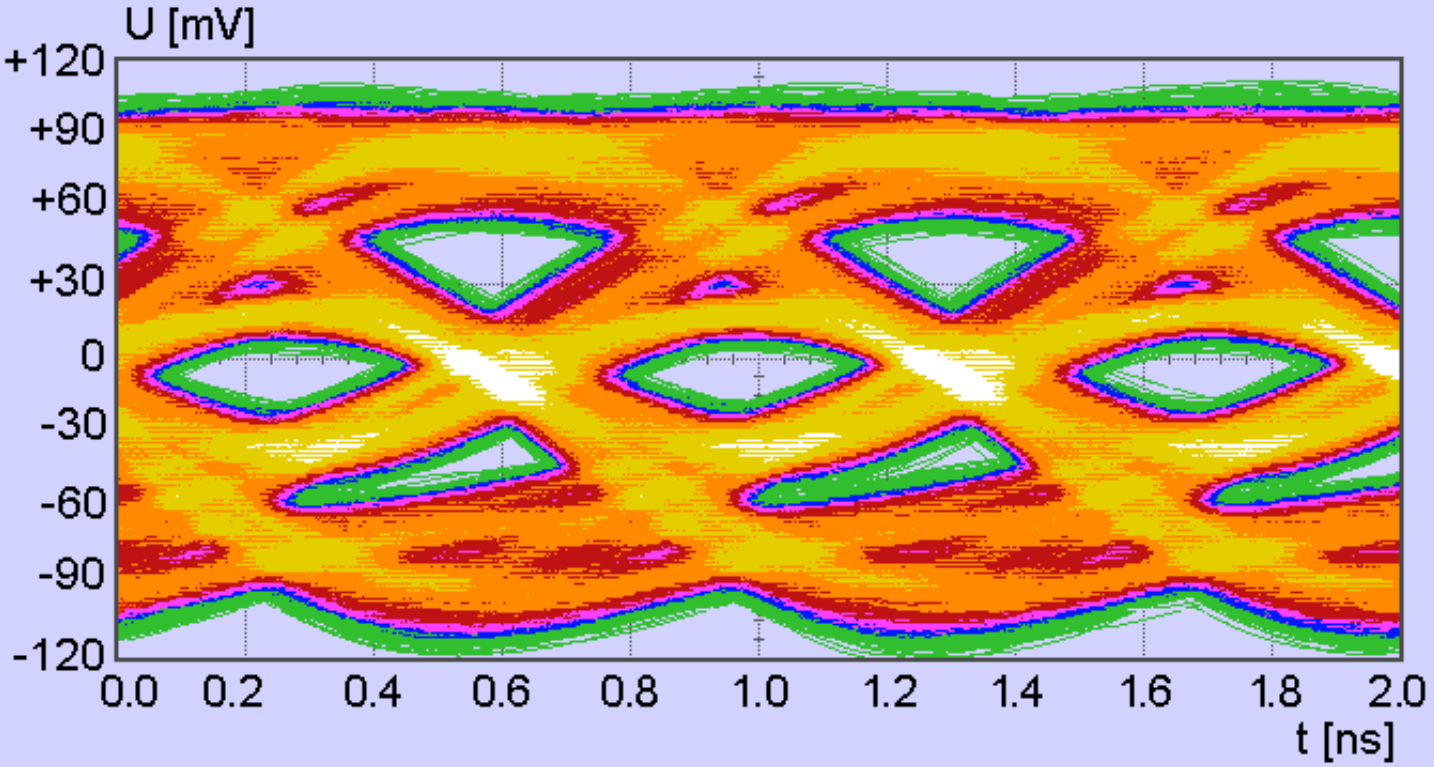


bit rate and penalty

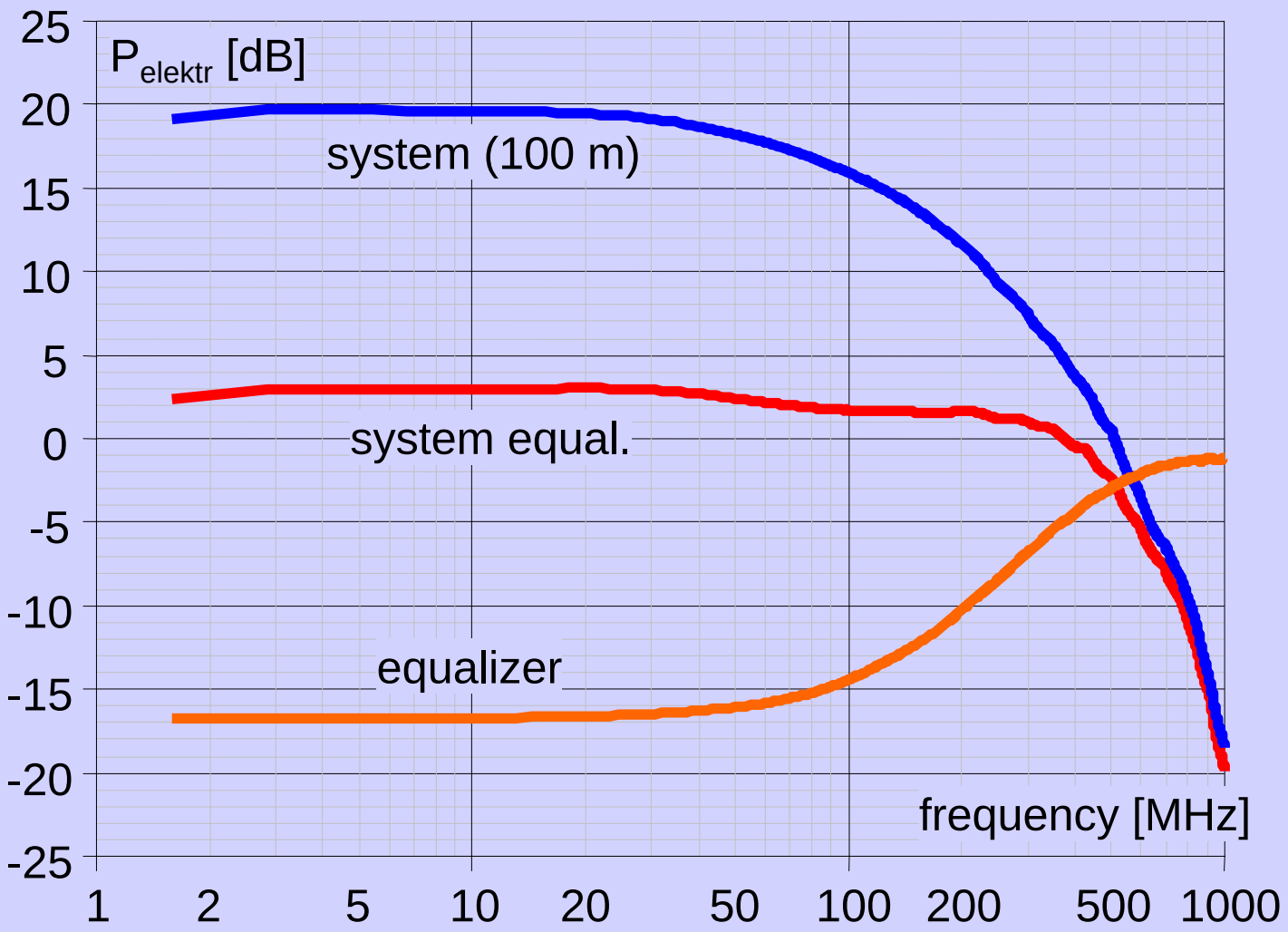


new: November 2007 POF-AC

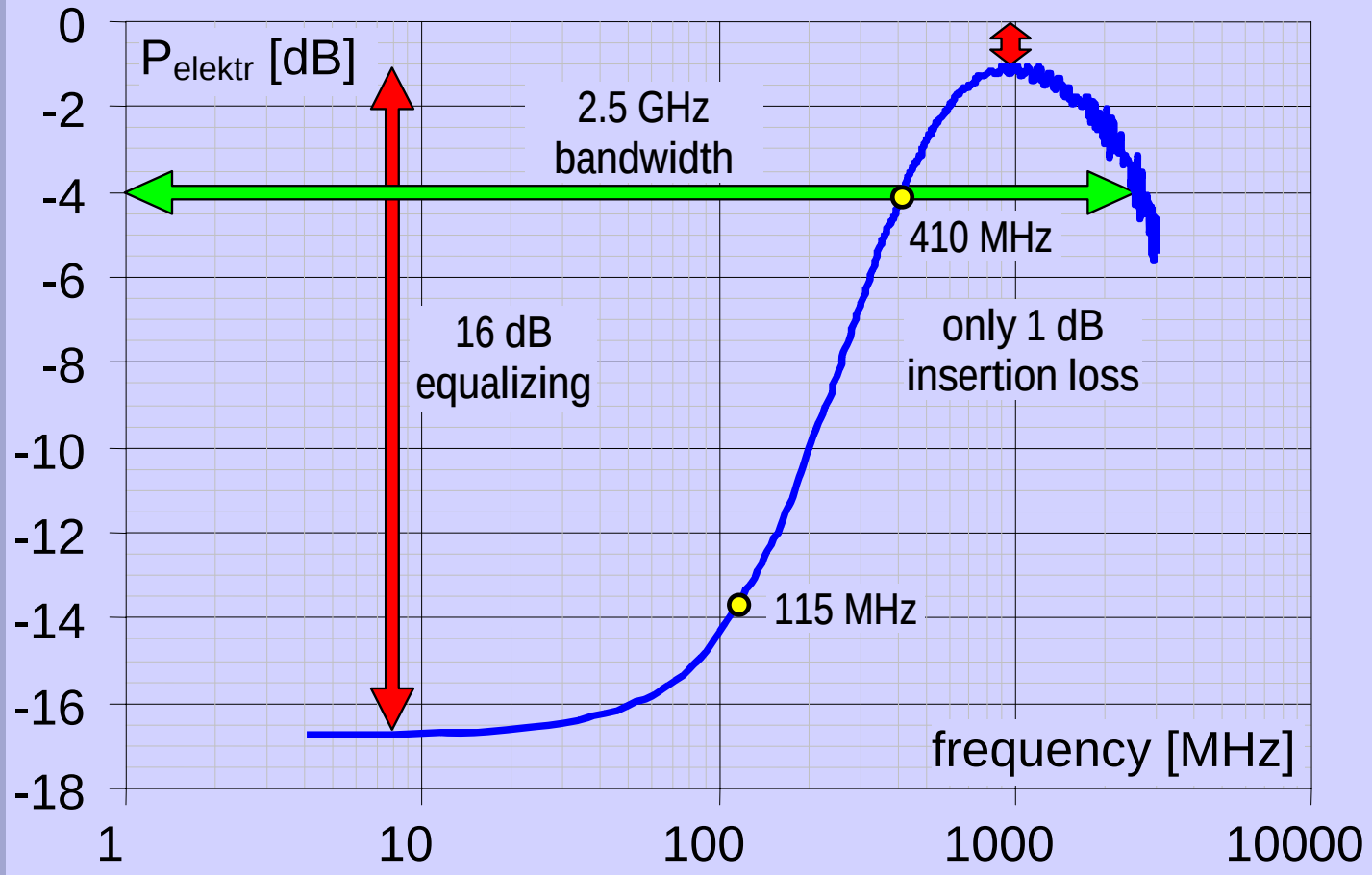
PRBS $2^5 - 1$; BER = 10^{-9}
improved passive high pass filter equalization
for 50 m at 1250 Mbit/s: 12 dB Margin



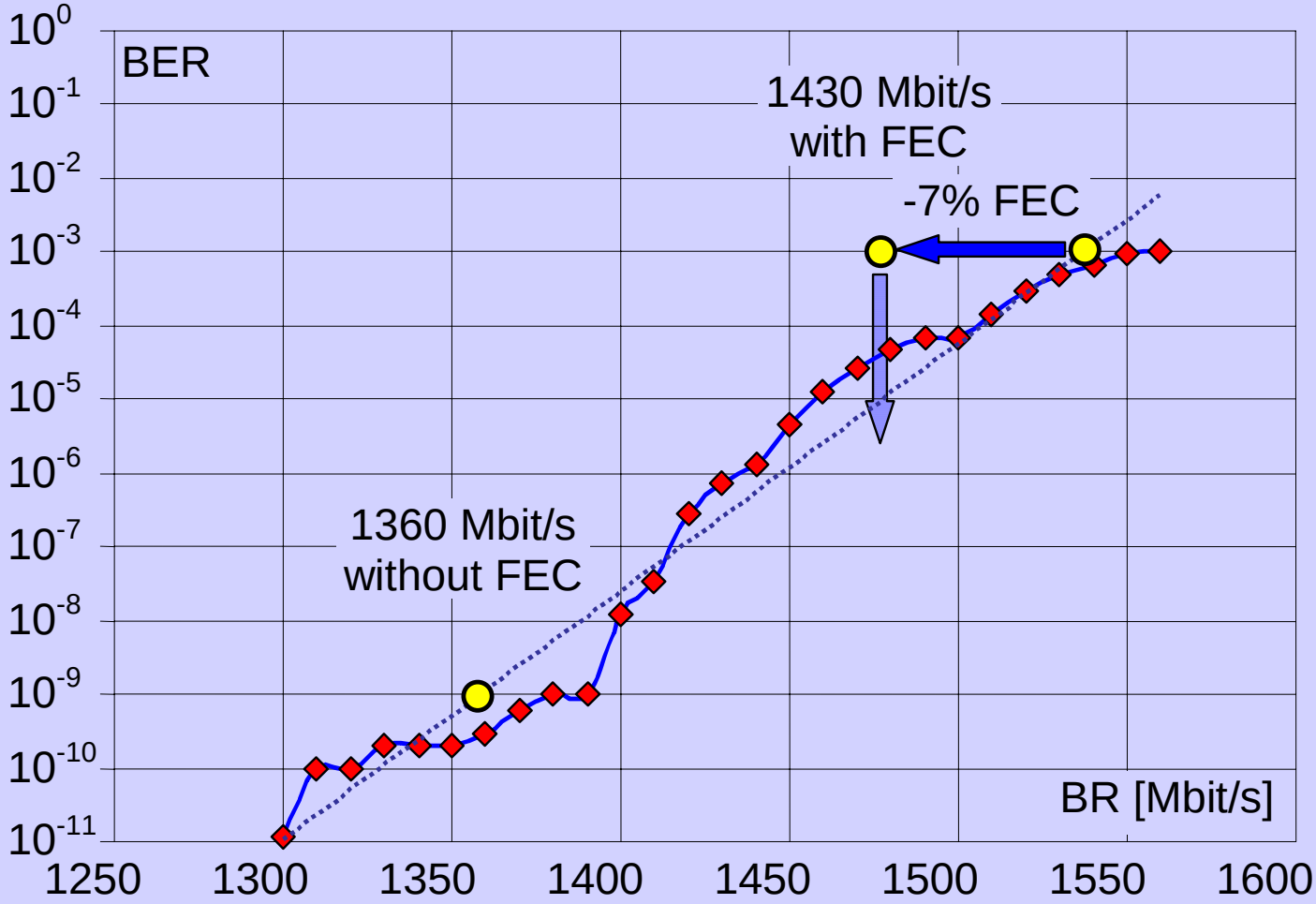
prinziple of the equalizer



hand-made equalizer

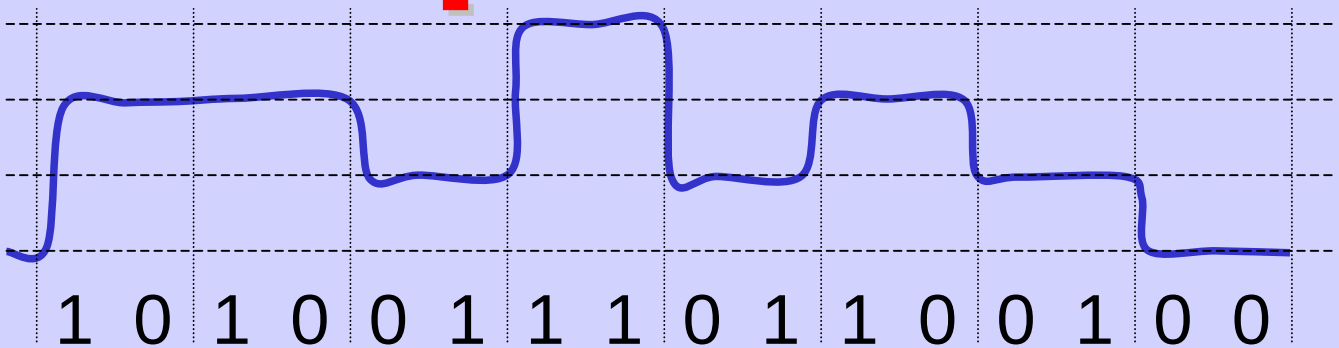


win by FEC ?


BER
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
1430 Mbit/s
with FEC
-7% FEC
1360 Mbit/s
without FEC
BR [Mbit/s]
1250
1300
1350
1400
1450
1500
1550
1600

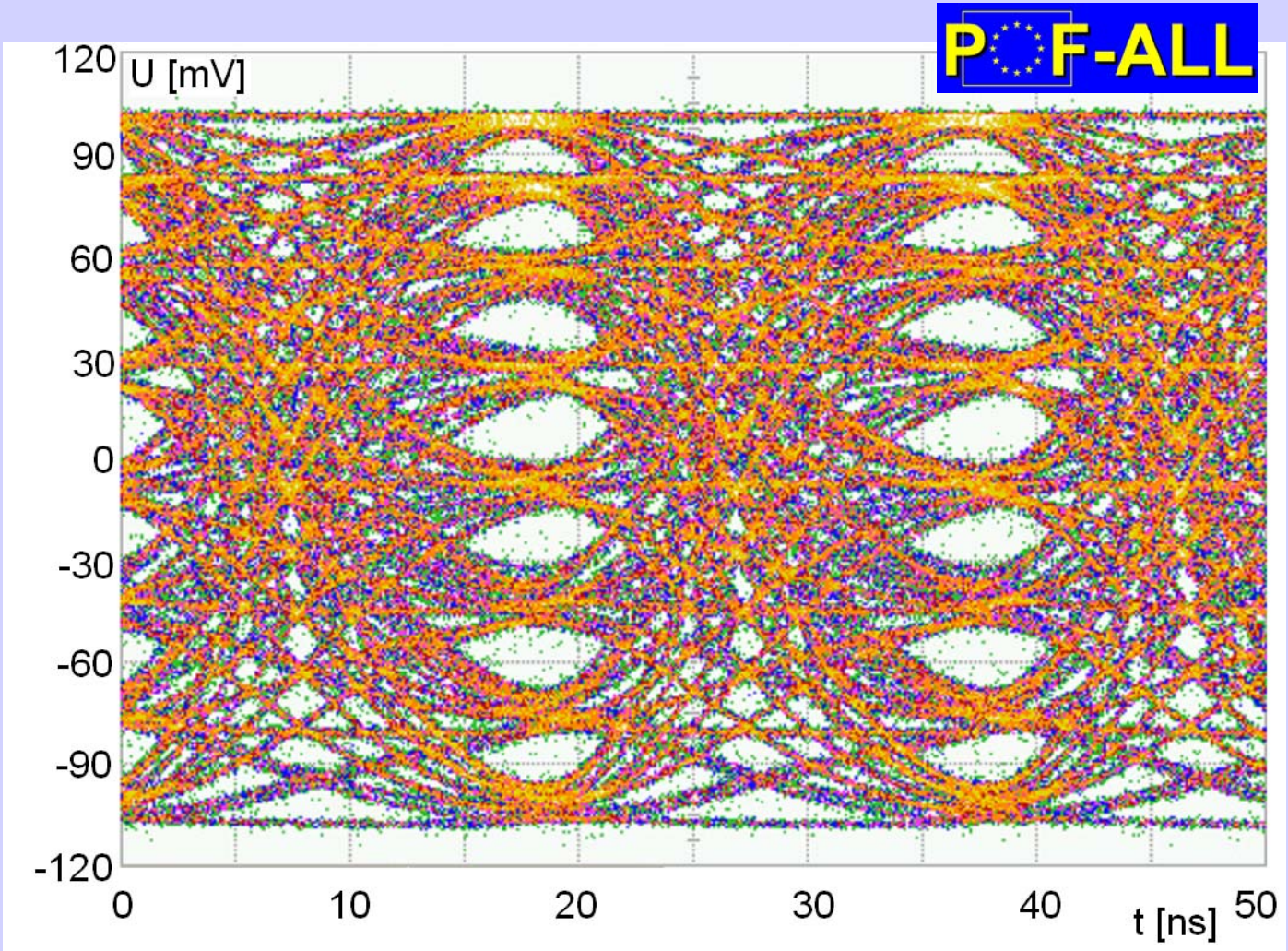
PAM

Pulse Amplitude Modulation



- direct modulation of LED/LD with several amplitude levels
- bandwidth demand is reduced by ld(n)
- linearity is very importent
- detection with multiple decision thresholds
- or detection with A/D conversion and digital signal processing

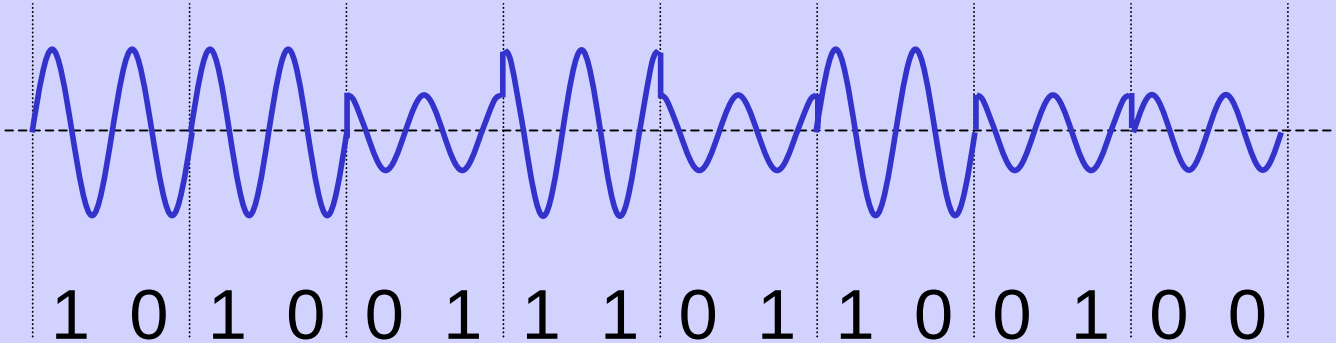
Example for multi level coding



ISMB Turin, 2007

QAM

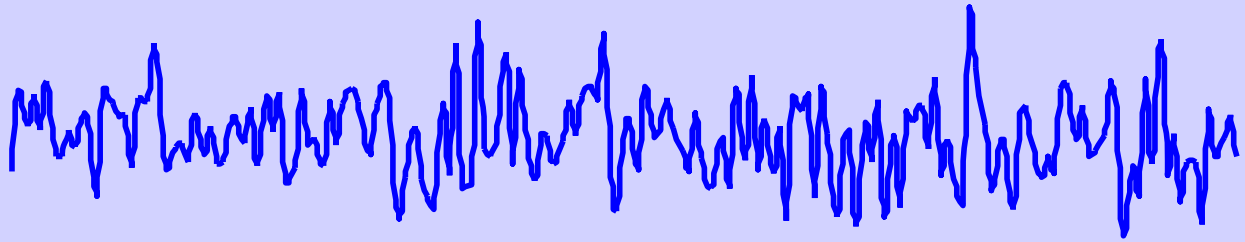
Quadrature Amplitude Modulation



- direct modulation of LED/LD with multiple amplitude and phase levels
- required bandwidth is reduced by 2·ld(n)
- linearity is very important
- detection with an quatrature receiver and several decision thresholds
- or detection with A/D converter and digital signal processing

DMT

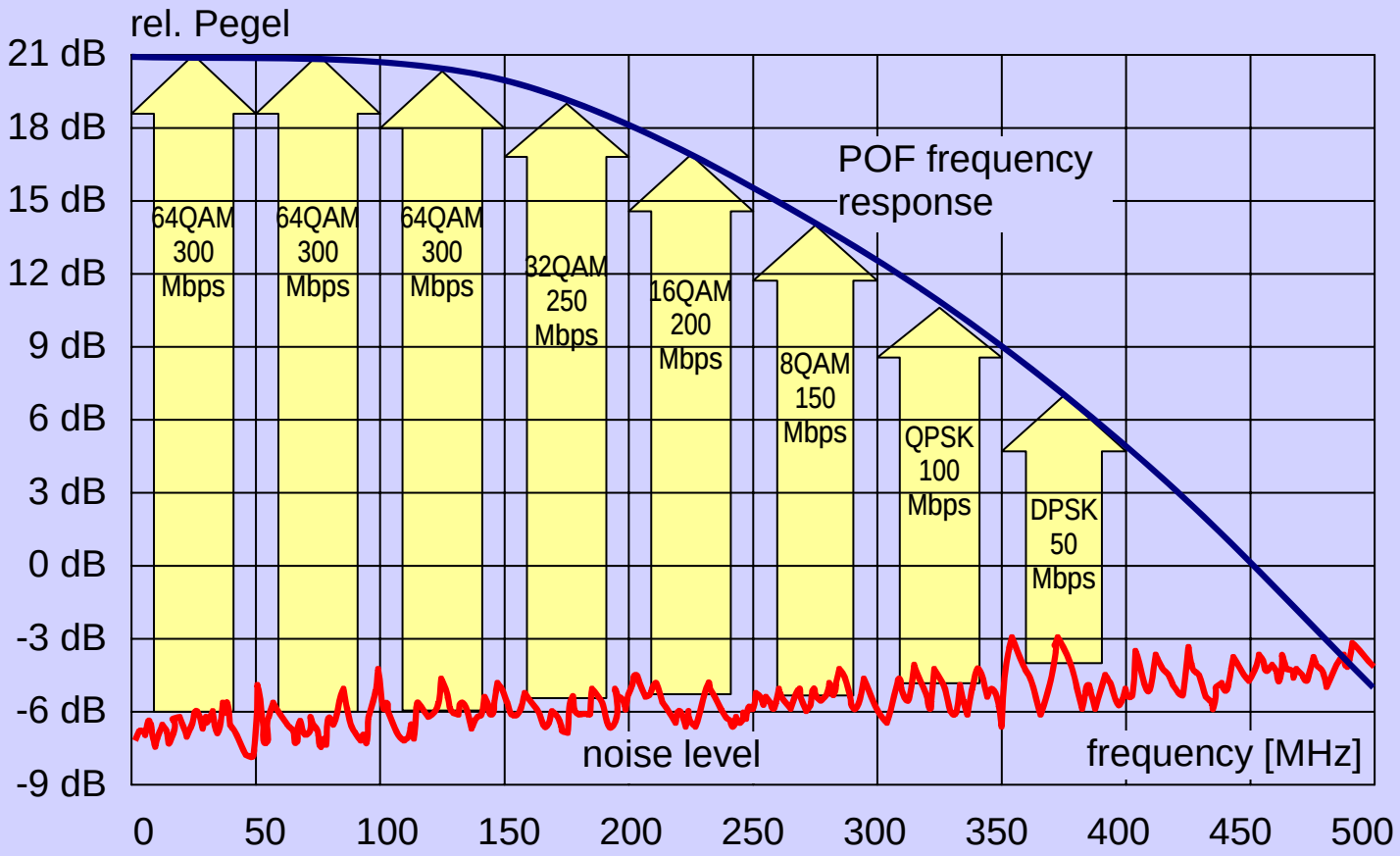
Discrete Multi Tone



1001110101001011101001010100110101101001100 0

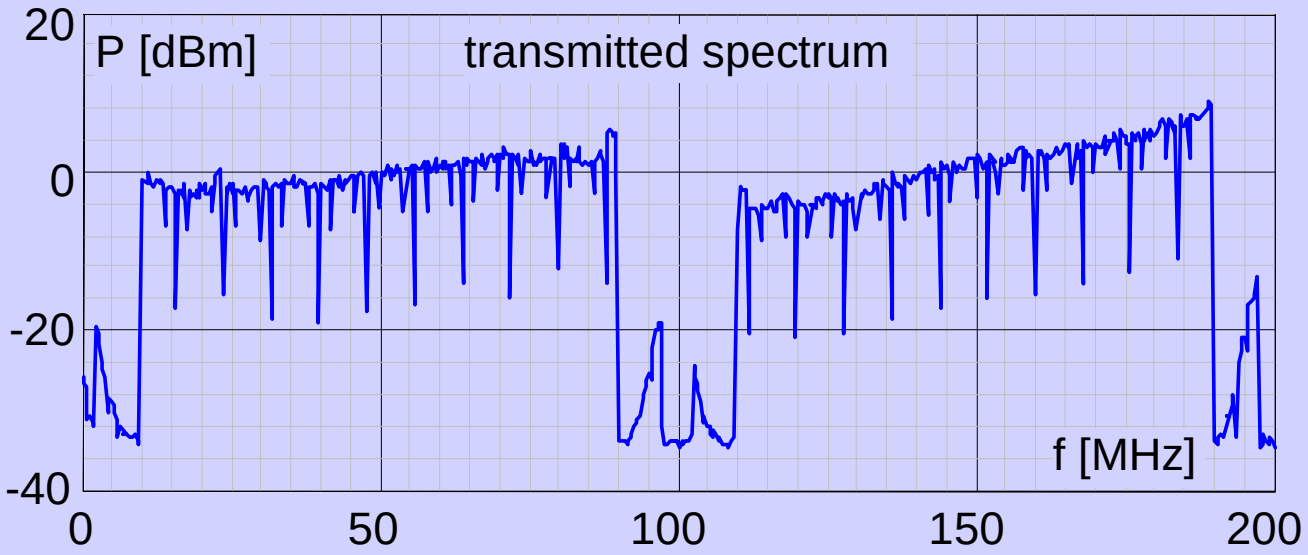
- direct modulation of LED/LD with multiple amplitude and phase levels on multiple frequency carriers
- required bandwidth is reduced by 2·ld(n)
- linearity plays a role
- detection with A/D converter and digital signal processing

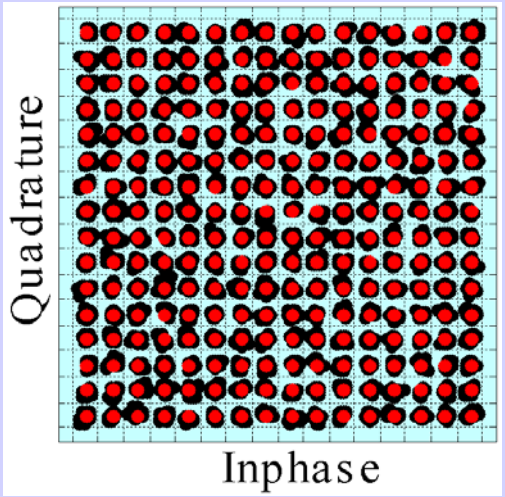
the principle of DMT

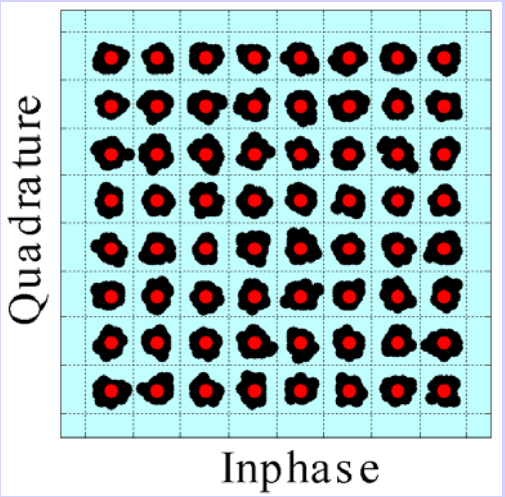


Optimal use of the transmission capacity requires low noise reveivers for high SNR

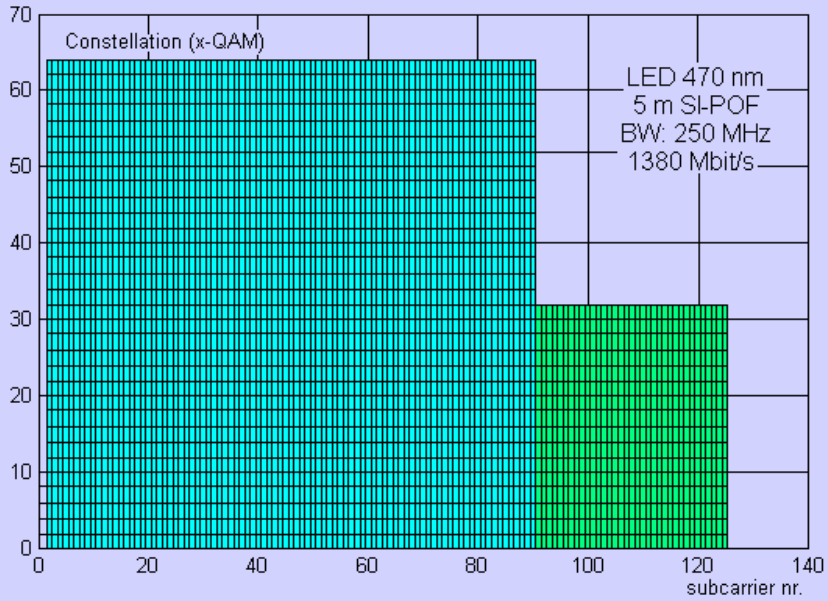
1 Gbit/s over 100 m POF (Siemens'07)

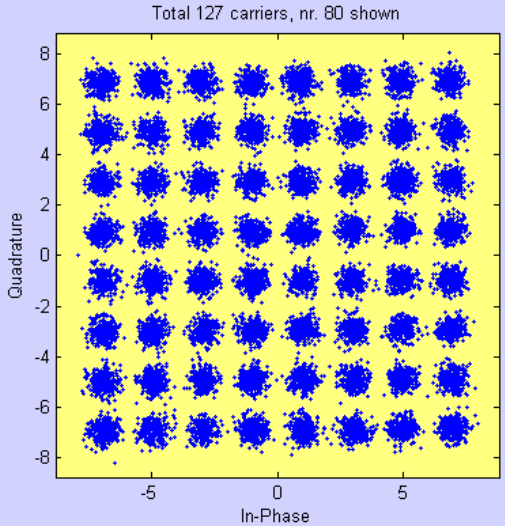


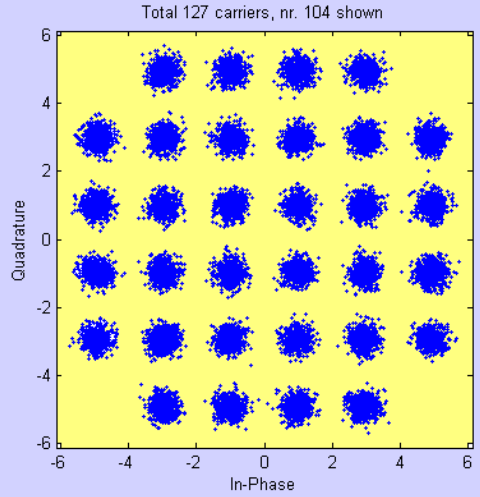




1380 Mbit/s over 5 m St.-SI-POF





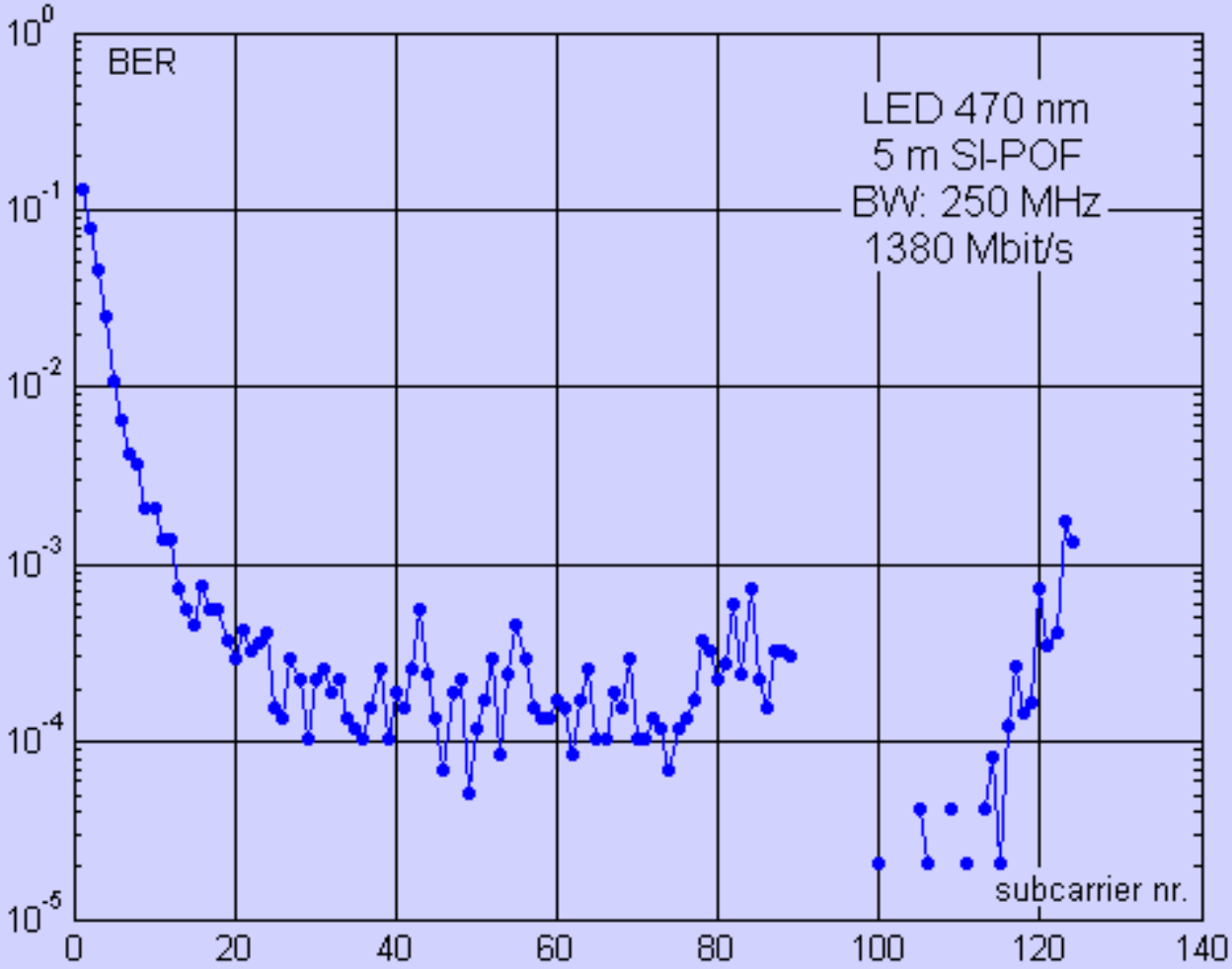


also:
1130 Mbit/s over 20 m
(net bit rate: 980 Mbit/s)
1106 Mbit/s over 50 m
(red LED, 993 Mbit/s net)

see OWB3

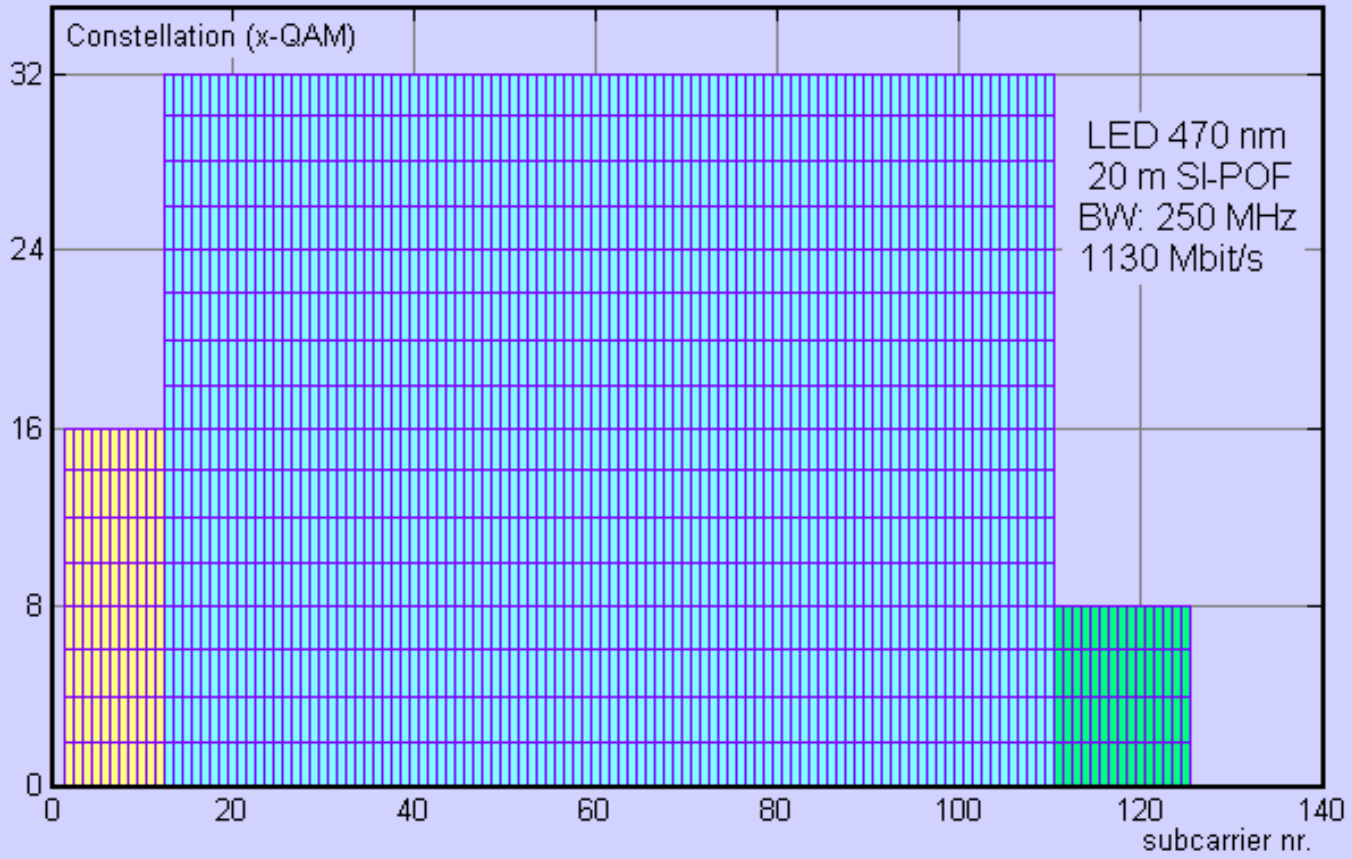
latest results, Gbps-LED (Siemens)

1380 Mbit/s, 5 m St.-SI-POF GH4001



requirements for DMT

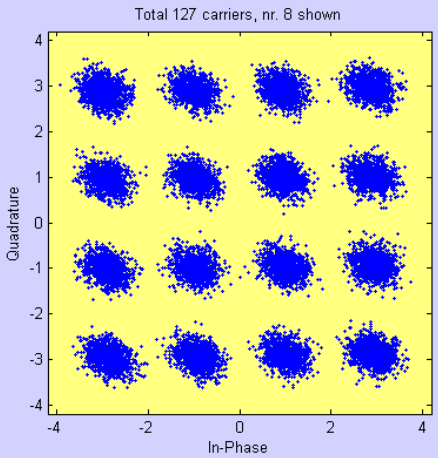
only 250 MHz required for 1 Gbit/s
better performance after LED nonlinearity compensation expected

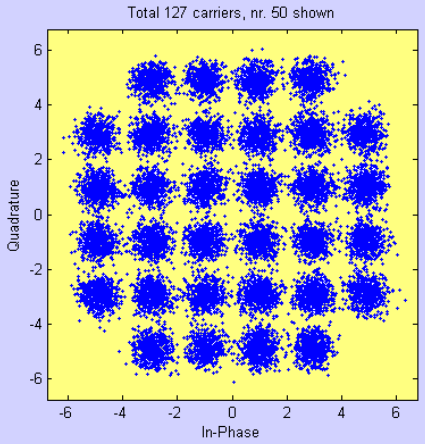


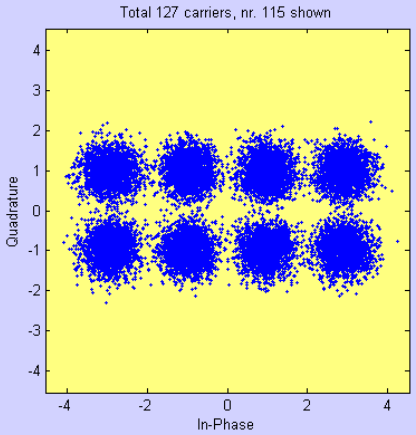
new results here on the OFC

see more details in papers OWB1 and OWB2

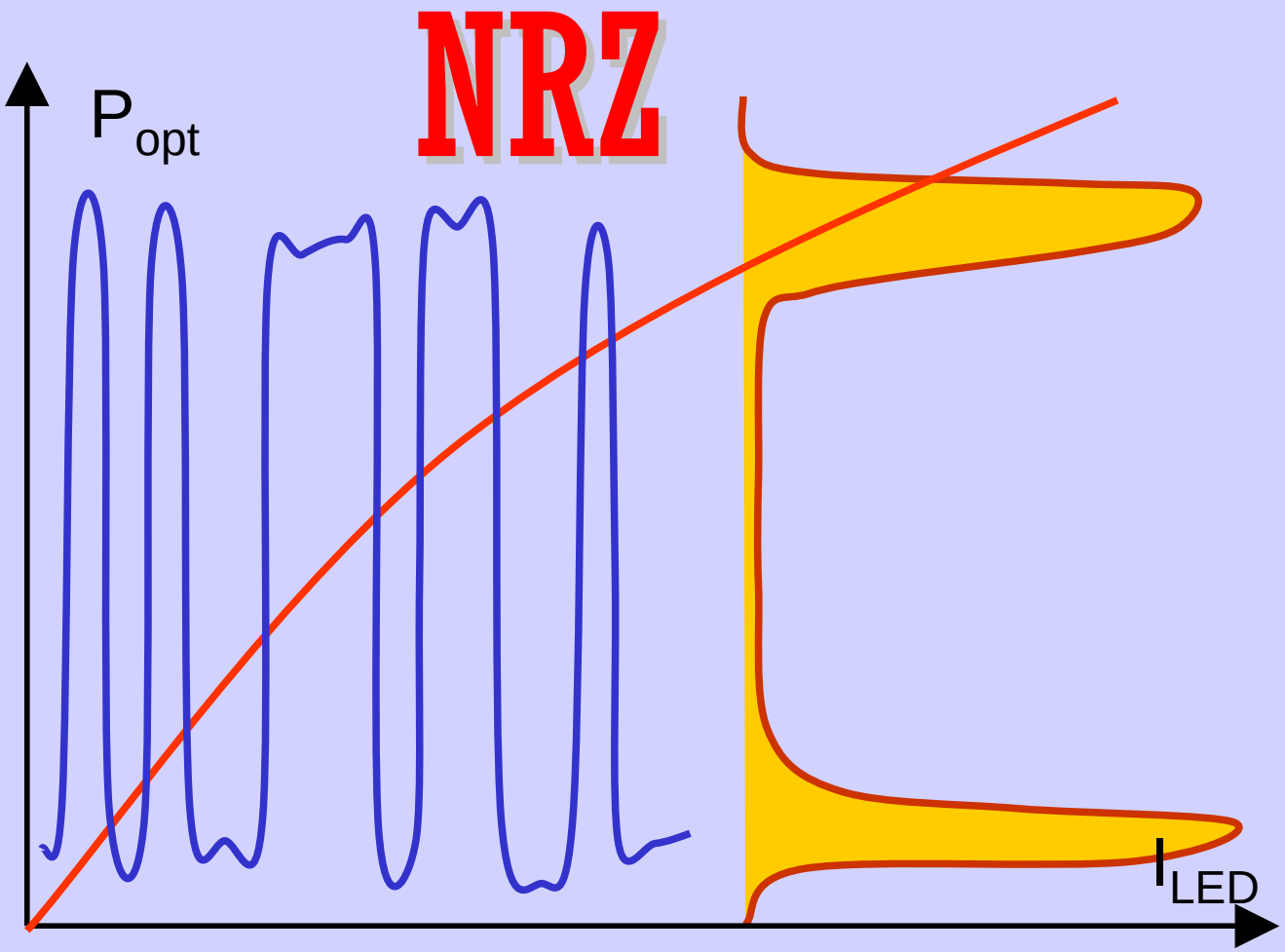
blue and red LED using DMT modulation
1380 Mbit/s, 5 m St.-SI-POF GH4001
1130 Mbit/s over 20 m
1106 Mbit/s over 50 m





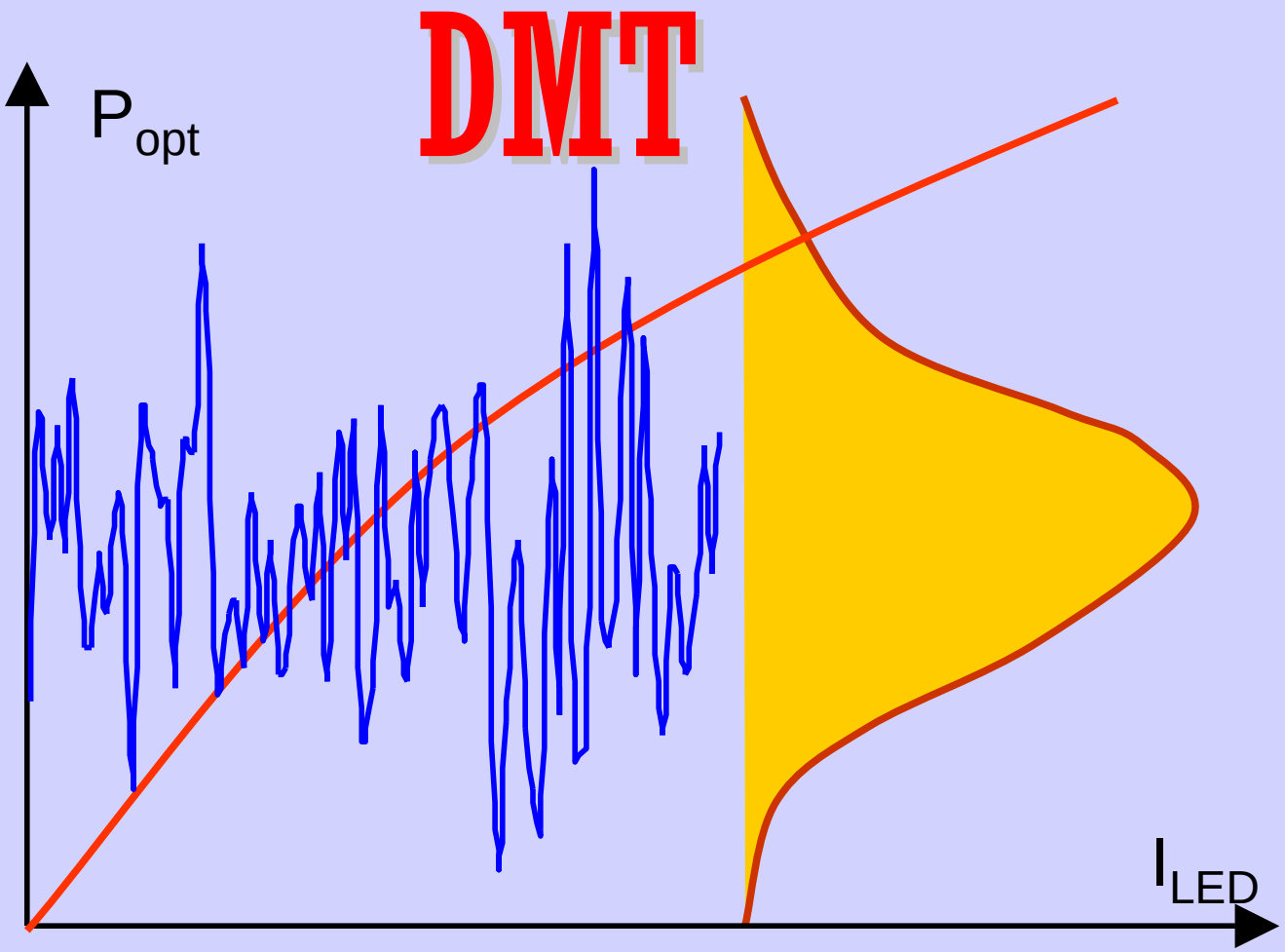


why is DMT not better ?



average modulation =
max. modulation

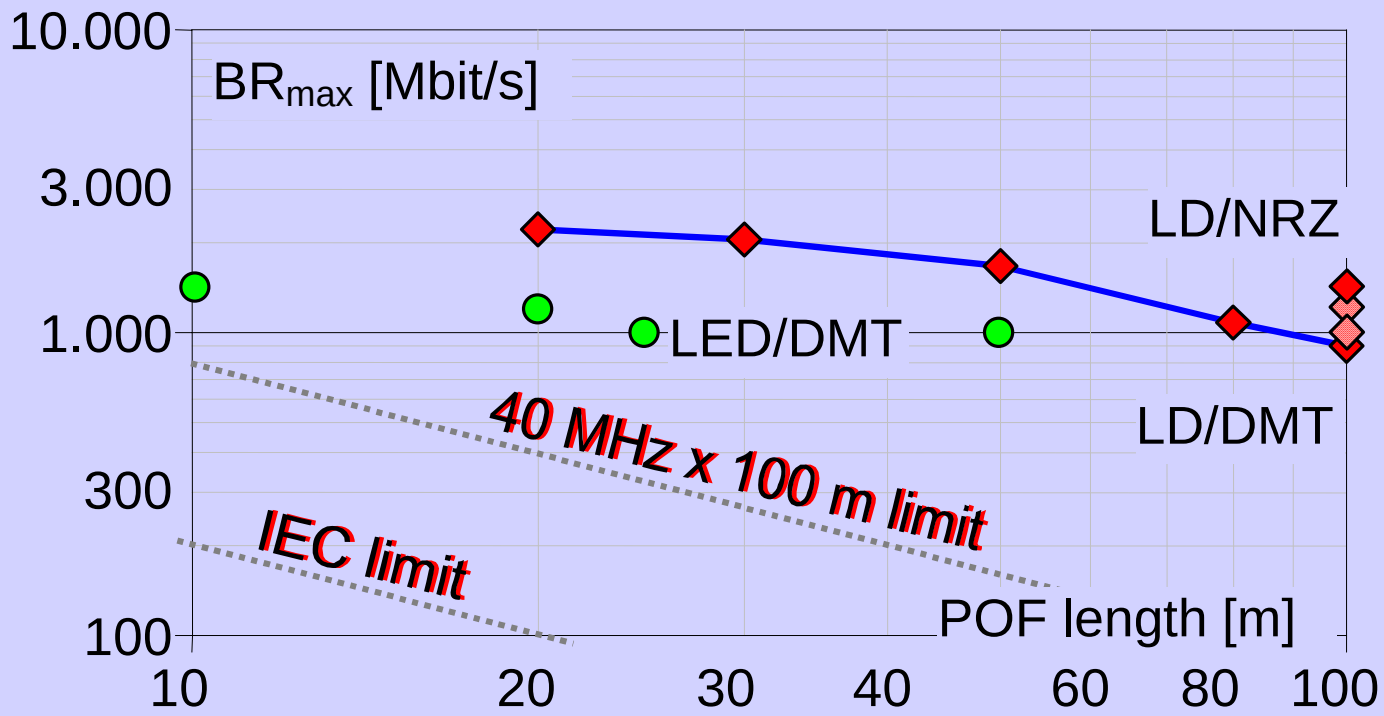
why is DMT not better ?



average modulation «
max. modulation

summary

overview SI-POF



conclusion:

1 Gbit/s over 30..50 m: simple with NRZ 1 Gbit/s over 100 m: will be possible in commercial products using more complex modulation scheems

consequences

- different modulation formats require different transmitters and receivers
- compaibility is nearly impossible
- complex methods are only profitable at high volumes

but:

- WLAN, PLC and DSL are with same compexity at least

comparison of the solutions

1250 Mbit/s over ≈ 60 MHz

passive equalizer	multi level modulation	digital filters (DFE; FFE)	multi carrier modulation