Similarities of PMD and DMD for 10Gbps Equalization

Moe Win
Jack Winters

win/jhw@research.att.com
AT&T Labs-Research

(Some viewgraphs and results curtesy of Julien Porrier)

Outline

- Polarization Mode Dispersion (PMD) in single mode fibers over long distances can create ISI similar to DMD
  - ISI due to PMD generates two pulses with random delay and amplitude - can cause eye closure
- Implemented Nonlinear Canceler (NLC)
  - 10 Gbps GaAs IC (fabricated by Rockwell)
  - 2-bit and 3-bit cancellation
  - 800 gates/5W, 1995

Outline (cont.)

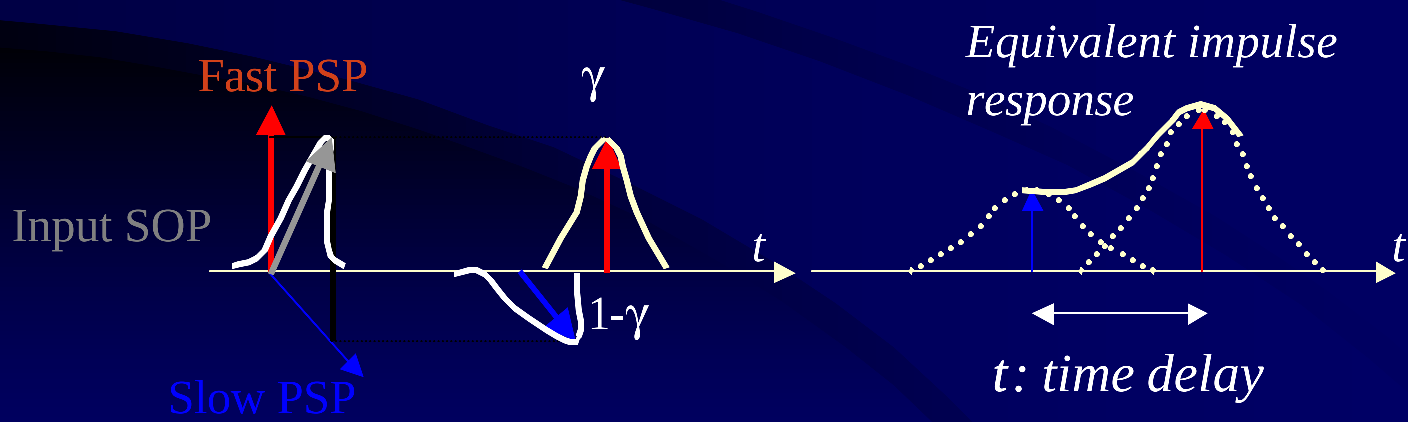
- NLC implemented (without A/D) using feedforward structure for speed:
  - 4 parallel decision circuits with manually set thresholds (also built 1.7 Gbps *fully adaptive* equalizer (1991) with discrete components)
  - Output chosen based on previously detected symbols
- NLC IC best for postcursor ISI
  - IC required external analog feedforward equalizer (FFE) to better mitigate precursor ISI
- NLC (versus DFE) mitigates nonlinear impairments such as ASE noise

Birefringence: group velocity

(very narrow spectrum => first order approximation)

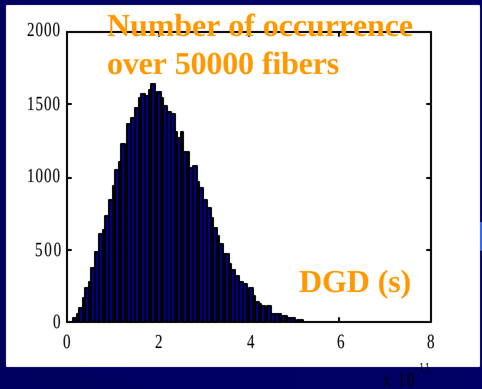
- x and y directions carried the different phase velocity
  => eigenstates of an phase velocity operator

- Eigenstates for the group velocity exist:
  Principal States of Polarization

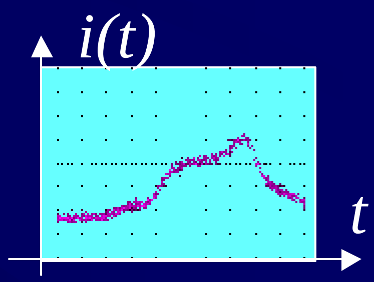


PMD characteristics

- PMD is a random process
  - γ has a uniform distribution
  - The Differential Group Delay (DGD)
    - Maxwellian distribution
    - Decays slowly => high probability of high DGD
    - Requires to have less than 1 dB penalty* at 3 times the <DGD>



- PMD is frequency dependent:
  - Channel per Channel mitigation
  - Nonlinear mitigation
  - Induces 14 copies of the pulses instead of 2:



Multipath channel similar to DMD

PMD mitigation requirements

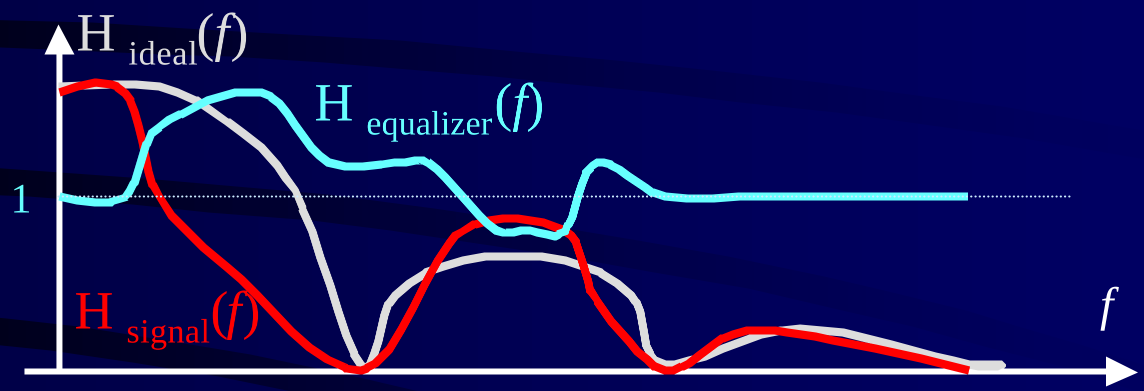
- PMD
  - Stochastic process
  - Amplitude γ:
    - Uniform distribution
  - DGD
    - Maxwellian distribution
  - Higher orders
- Mitigation
  - Adaptive
  - keep 1dB penalty even at high DGD
  - Channel per channel
  - Nonlinear effects
  - Cheap
  - Transparent
  - Global improvement

Electronic Mitigation

- Linear Equalization
  - Principle
  - Performances
  - Implementation
- Nonlinear Cancellation (NLC)
  - Principle
  - Performances
  - Implementation
- Experimental verification
- Performance degradation in case of Optical Noise

Linear Equalization

- Principle:



  - Time domain: add and subtract copies (Laplace transform of the inverted channel) of the signal to itself to remove ISI
  - Frequency domain: filter the received signal to recover the ideal spectrum (if linear impairment)
  - Note: always enhance the noise

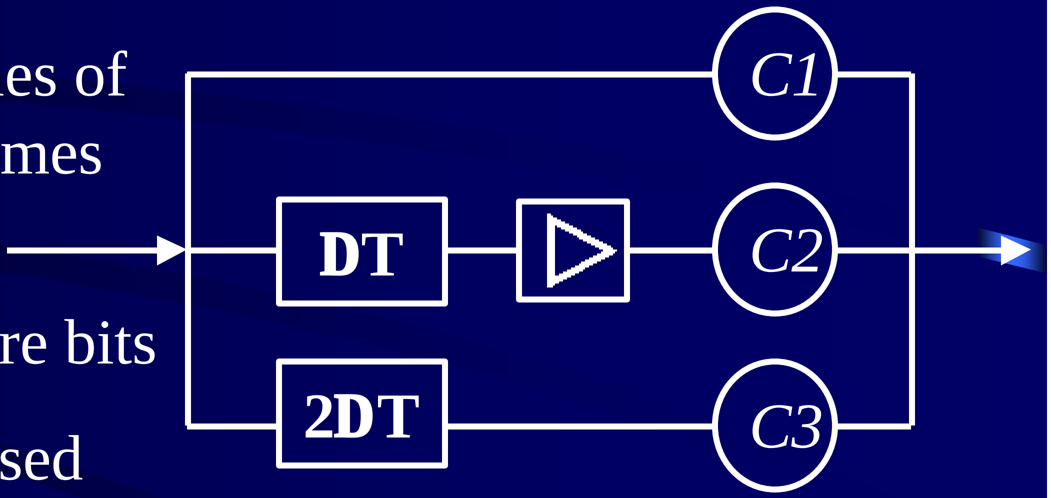
Feed Forward Equalizer

Feed forward equalizer

•Add and subtract retarded copies of the signal to itself at different times (tap delay lines)

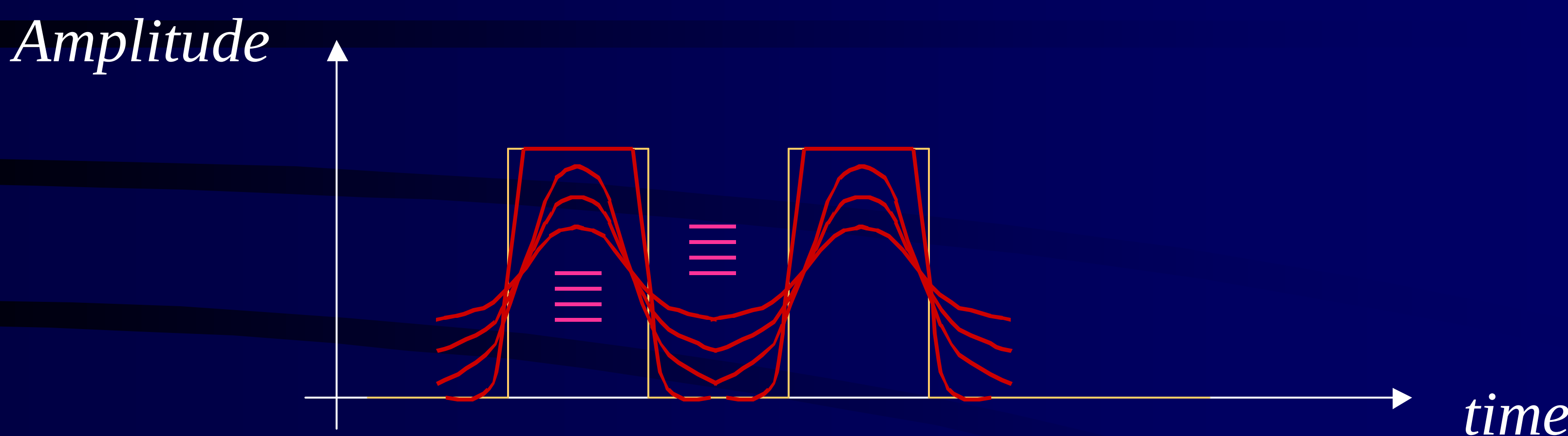
•Suppress linear ISI due to future bits

•Does not work if the eye is closed



ISI: InterSymbol Interference

Nonlinear Canceler (NLC)



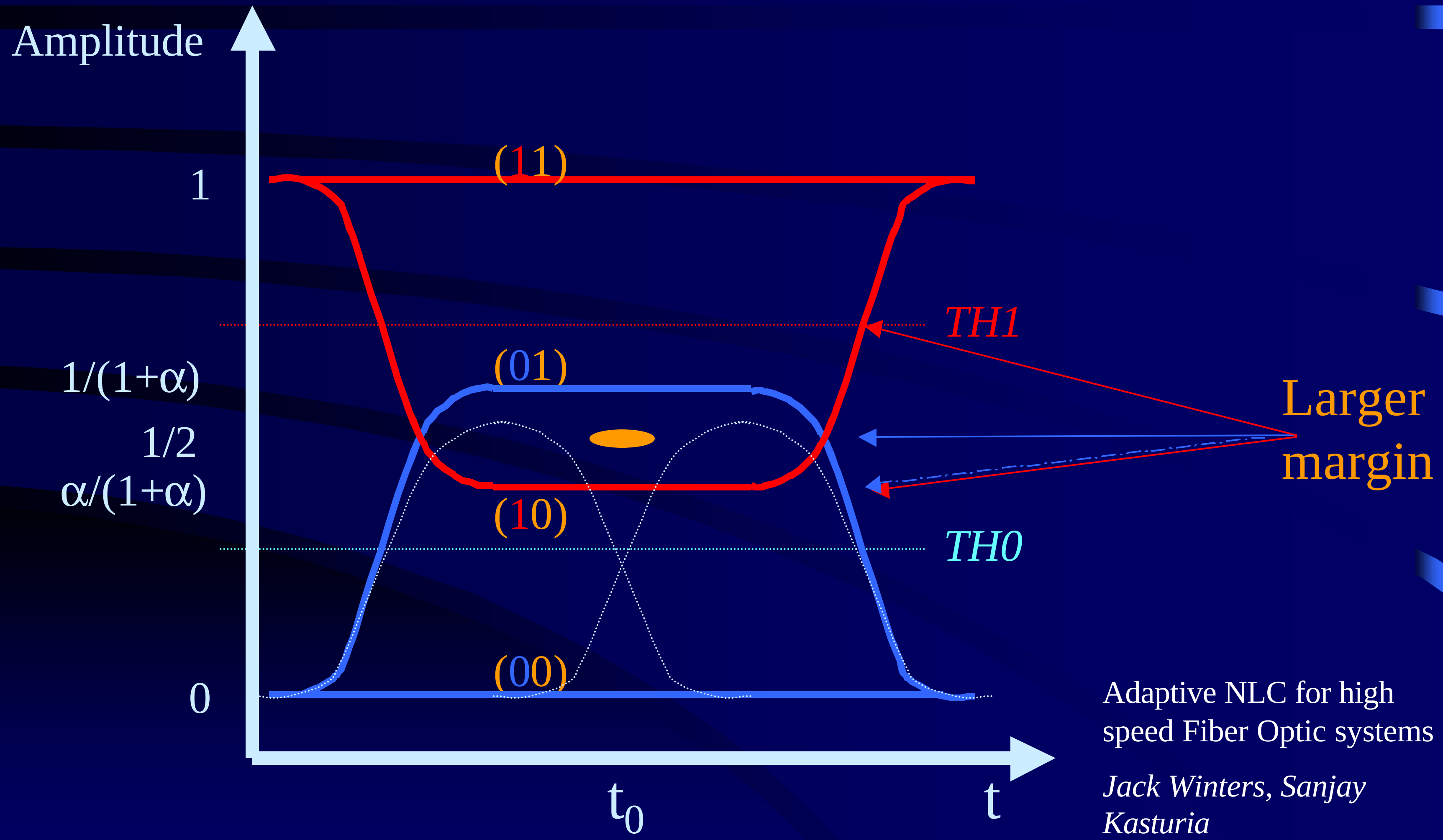
- Principles:
  - Adapt the threshold to the ‘situation’ (ISI)
    - ISI from previous bit : **S(k) = x(k) + a · x(k-1)**
    - normalization : **S(k) = (x(k) + a · x(k-1))/(1+a)**
    - pattern dependent optimum thresholds :

TH1 = 1/2 + a/(2+2a)

TH0 = 1/2 - a/(2+2a)

(at the midpoint of the expected values of 1 and 0)

4 levels eye for α ≈ ¾: Optimum thresholds



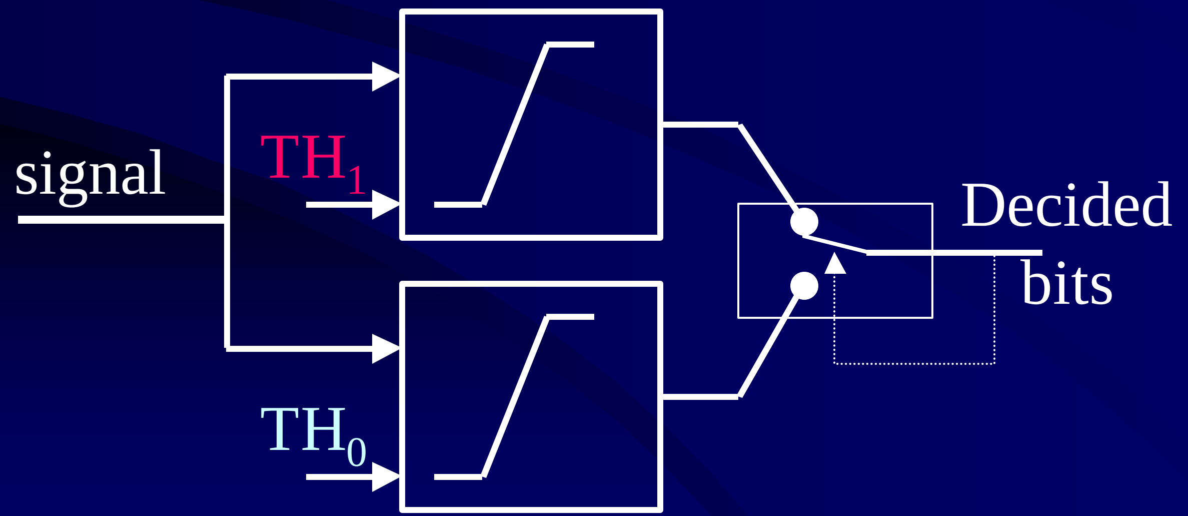
Adaptive NLC for high speed Fiber Optic systems

Jack Winters, Sanjay Kasturia

JLT Vol 10 No 7 July 1992

Consequences

- Limits:
  - 3 dB power penalty when the eye is closed (worst case)
  - Does not consider future bits => FFE is needed
- Implementation:

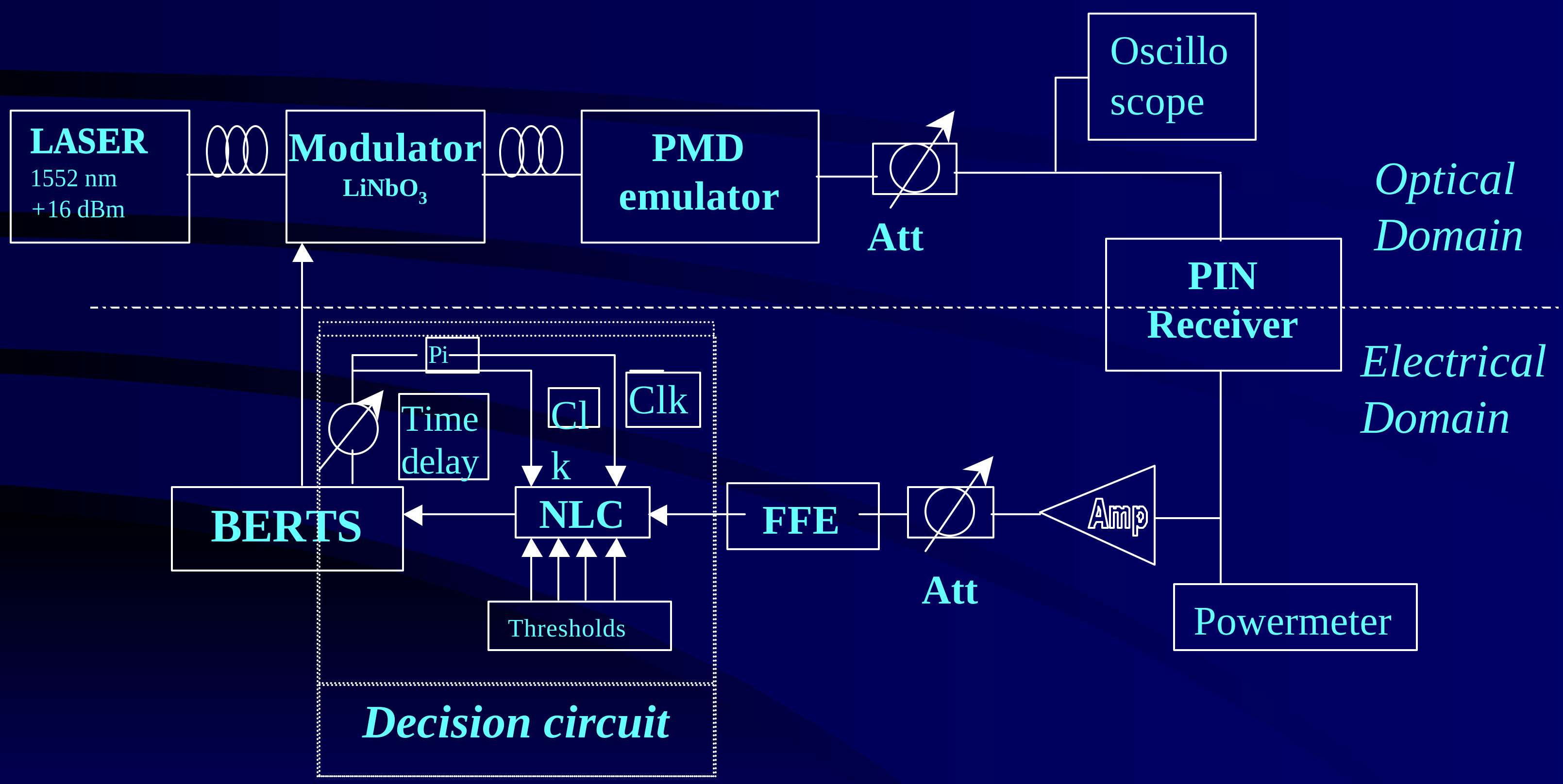


Performance

- Experiments:
  - Demonstrate the improvement given by the 2-bit canceller

    (a device considering only the two previous bits)
  - Verify our simulation for generalization
- Principle:
  - 10 Gbits/s transmission
  - First order PMD
  - Measurement of the reduction in penalty given by the NLC

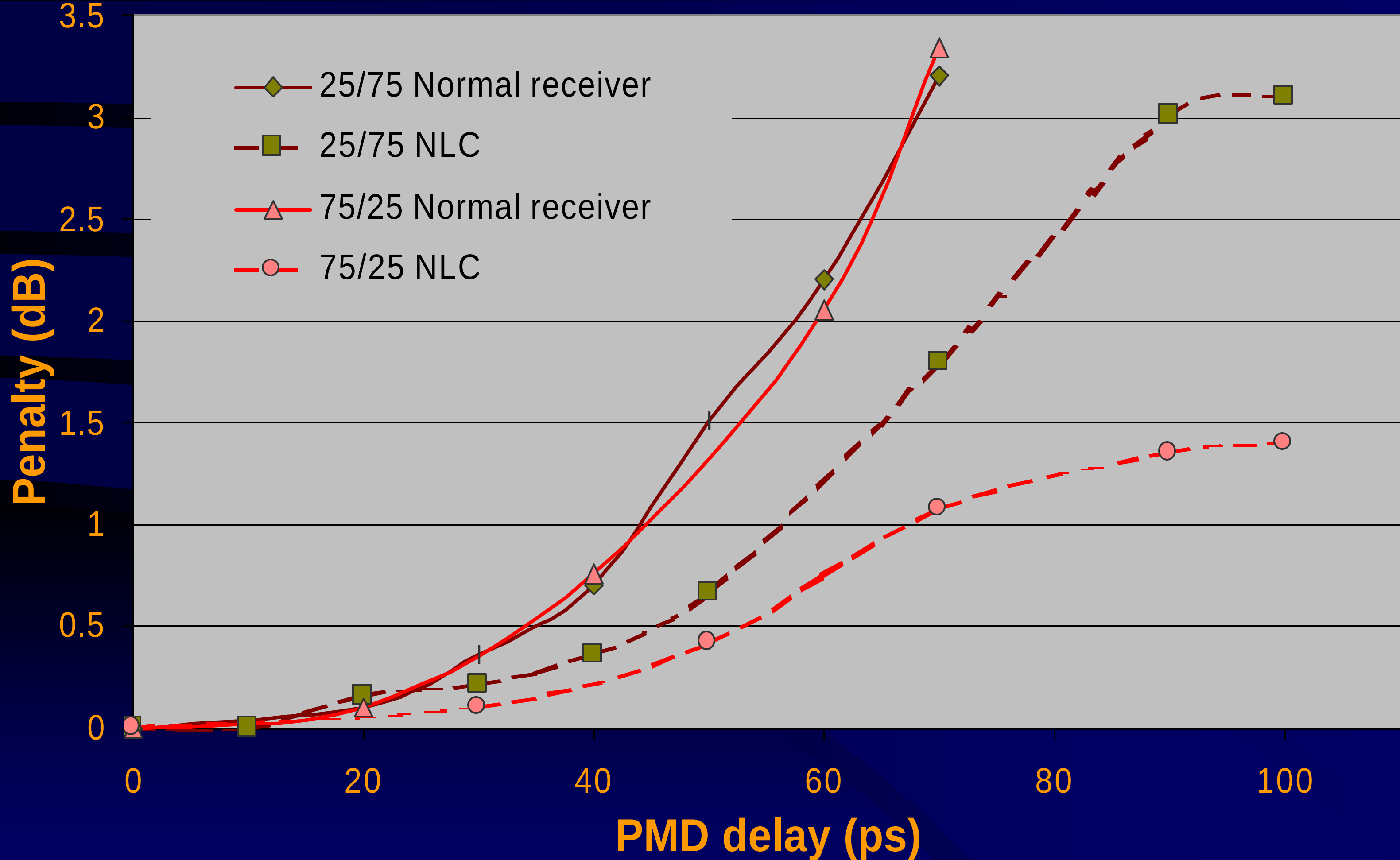
Set up



LASER
1552 nm
+16 dBm
Modulator
LiNbO3
PMD
emulator
Att
Oscillo
scope
Optical
Domain
PIN
Receiver
Electrical
Domain
Pi
Time
delay
Cl
k
Clk
BERTS
NLC
FFE
Att
Amp
Thresholds
Powermeter
Decision circuit

Asymmetrical behavior of the NLC

Comparison of the experimental results for 25/75 and 75/25 at 10 Gb/s



Summary

- In the thermal noise limit:
  - The NLC has a maximum 5 dB penalty for first order PMD
  - The Compound NLC+FFE has a maximum 4 dB penalty
  - The 1 dB penalty point is pushed from DGD of 50 ps to 65 and 70 ps
- These penalties will replace ISI penalty of current link model, and possibly others
- Equalization techniques may be viable for DMD channels