Towards 300m & Beyond with 10GBASE-LRM:
Experimental Demonstrations on Technical Feasibility

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Agenda

- **Towards 300m for 10GBASE-LRM: EDC Technical feasibility perspectives and challenges.**
- **Worst-case FDDI-grade (Cambridge Rel 1.0) MMF channels and emulation**
- **Experimental demonstrations on performance and feasibility with fully adaptive EDC (SCN3142) at 300m with Cambridge Fibers.**
- **Discussion on 220m to 300m reach extension v/s implementation penalty.**
- **Conclusions**

EDC: Technical Feasibility Perspectives
Towards 300m

- **10GBASE-LRM developing with minimum of 220m over FDDI-grade MMF.**
  - **Provides for wide implementation scope of EDC (including FFE)**
  - **Allows for reasonably high implementation margin.**
- **Major EDC vendors working on higher performance EDC's**
  - **Allows for 300m and above for large percentage of FDDI-grade MMF links.**
  - **More stringent implementation margin is allowed for.**
  - **Adaptation is challenging; needs careful attention in design.**
  - **Low power and small form-factor IC's implementable – aggressive enough for low-power XFP. Easily fits within XENPAK/X2 module form factors.**

EDC: Technical Feasibility Perspectives
Towards 300m - Challenges

- **Signal processing datapath needs to be high performance. Linear equalizers such as FIR-based or IIR-based will not provide sufficient performance. A challenge here may be to design high-speed feedback loops – mature techniques known in literature.**
- **Equally critical and possibly, more challenging, to design the datapath so that the adaptation figure of merit is convex function of datapath coefficients. Needed for plug & play.**
  - **Doesn't matter if adaptation is digital or analog!**
- **Adaptation circuitry for adapting datapath coefficients and front-end AGC**
  - **Careful trade-off between tracking error variance and adaptation time constant. This topic has been well studied in literature.**

Technical Feasibility Demonstrations within IEEE802.3aq

- **Extensive simulation-based results showing feasibility with classical EDC architectures within current link budget over 300m+ with implementation margin (>1 dB)**
  - **using Cambridge model (multiple versions)**
  - **802.3z MBI data set.**
- **Several experimental results showing feasibility over 300m+**
  - **Worst-case SX fiber (using silicon circa Q2, 2003, EDC power penalty < 5 dB)**
  - **OM3 fibers (with IEEE offset launch, which can be challenging, EDC power penalty < 4 dB).**
  - **TIA 12/96 demo fibers**

Experimental Demonstrations of 10GBASE-LRM at 300m: Cambridge Model Fibers

- **Selected limited number (3) fibers from Cambridge Model Release 1.0**
  - **Covers all three: precursor, postcursor and quasi-symmetric impulse responses**
  - **Same as considered by Petre/Piers in proposing static stressed compliance test for 10GBASE-LRM.**
  - **Specifically,**
    - **f18o17 (postcursor),**
    - **f48o17 (precursor)**
    - **f42o20 (quasi-symmetric)**
- **Reaches of 220m and 300m : measure of reach v/s implementation penalty**
- **Experiments with full adaptation of EDC – *NO manual tuning of any kind*.**

Test Set-up

Broadband Noise generator

Pre-slicer I/p waveform

Pattern Generator

Cambridge MMF emulator

LPF (5GHz)

EDC

CDR

10.3125 Gbps
PRBS 2^{31}-1 NRZ

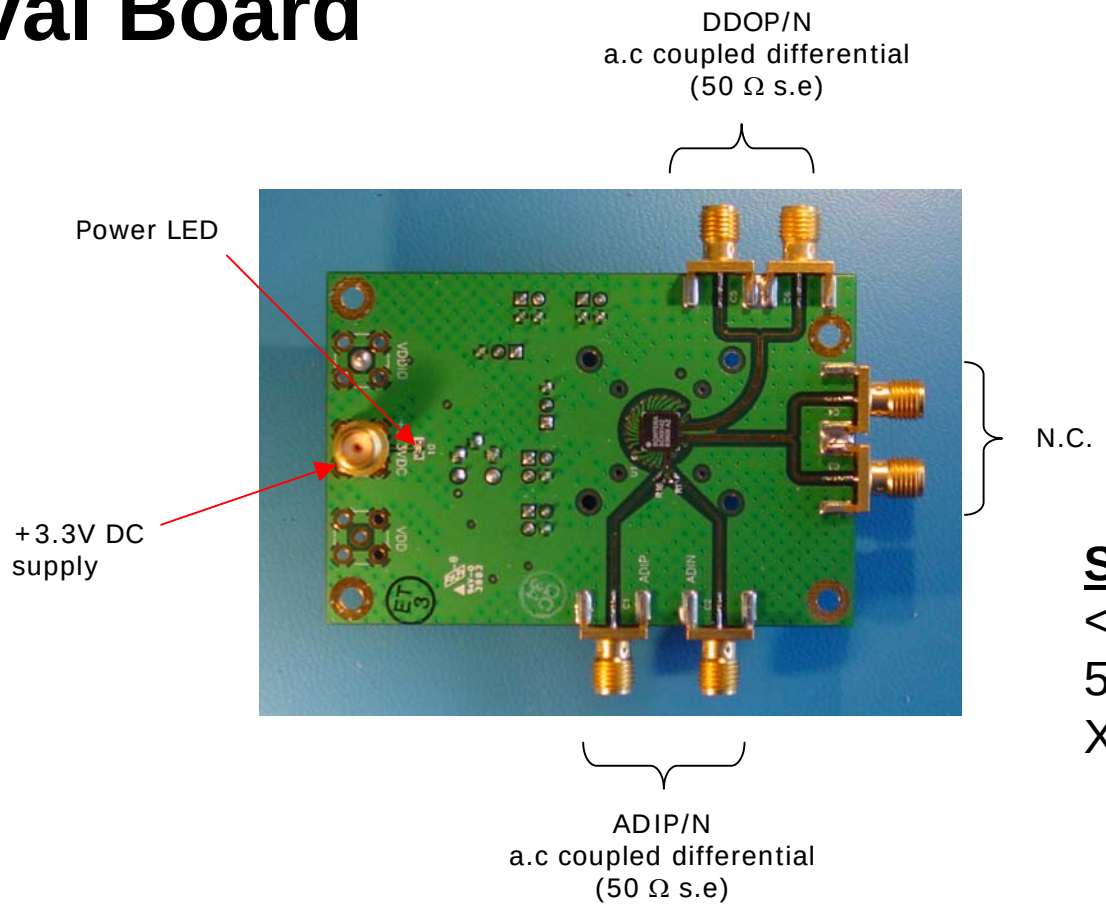
Emulates laser Rise/fall times, ROSA b/w

DATA

CLK

Error Det.

EDC Eval Board



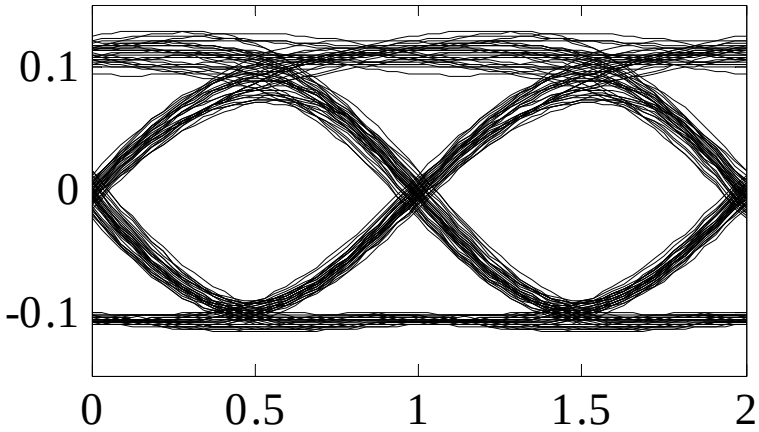
SCN3142:
<500mW
5mmX5mm QFN
XENPAK, X2, XFP

Fully blind adaptive configuration without any manual tuning of coefficients.

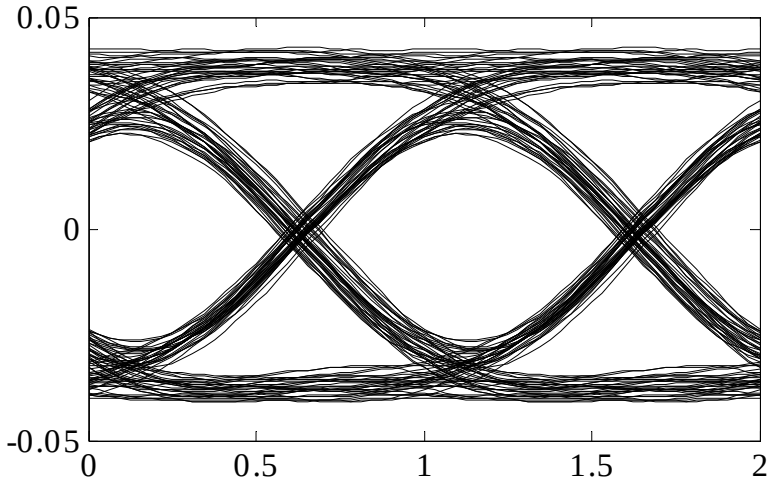
MMF Electrical Emulator

- **8-tap FIR filter with <50ps tap spacing cascaded with LPF (bw < 3-4 GHz).**
- **Tap coefficients selected so as to minimize the mean-squared error between actual channel and emulated channel.**

Test Set-Up: Back-to-Back



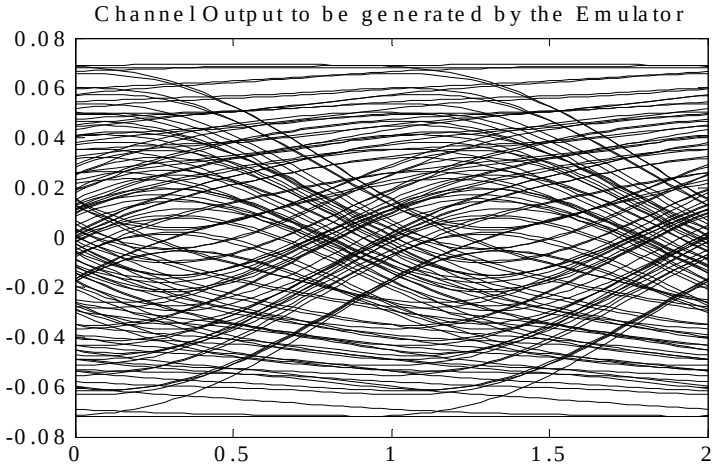
optical back-to-back eye diagram



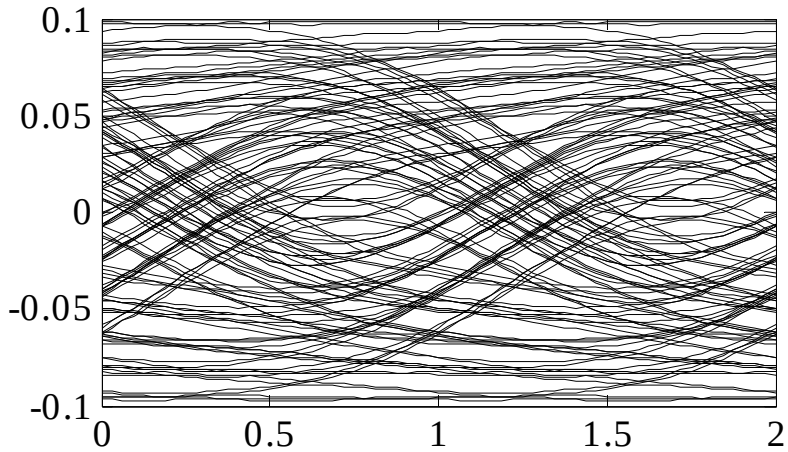
emulated channel, EDC input

Noise set so that for back-back (without LPF) electrical SNR of 16.6dB to achieve BER of 10^{-11} (with LPF, SNR of 19.2 dB required)

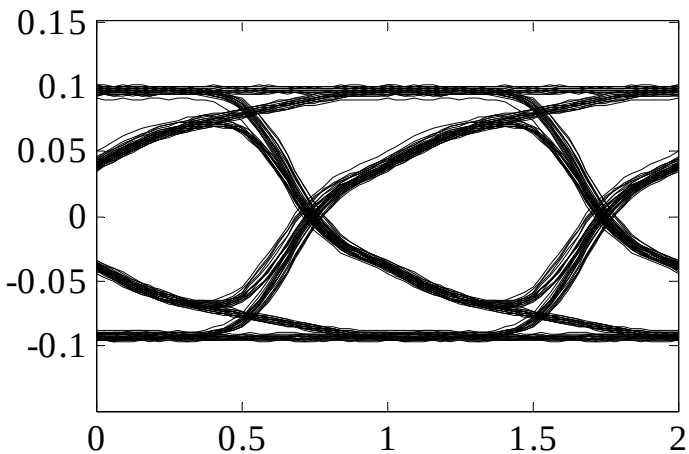
Cambridge-Model Fiber #1 : f18017
Reach: 300m



original channel, 10.3125Gb/s



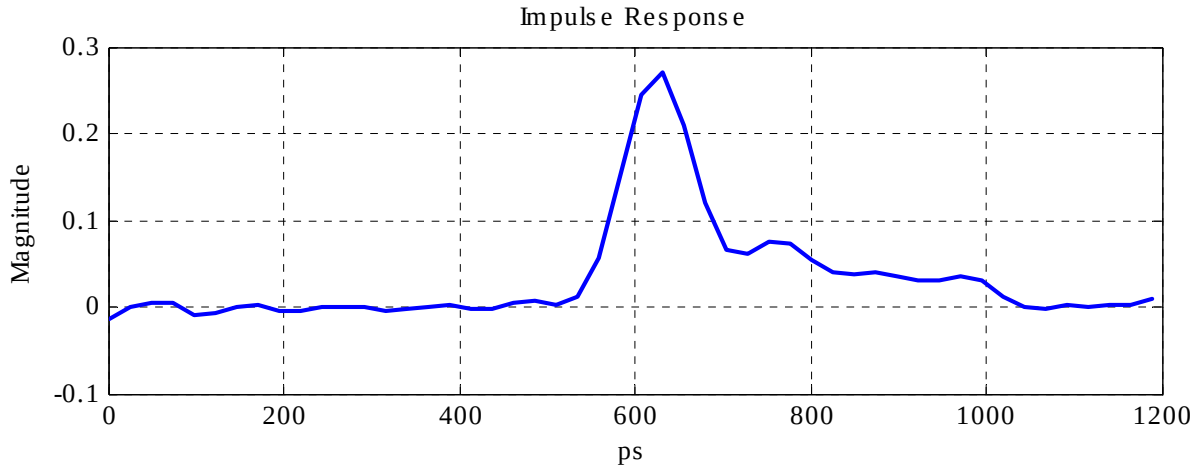
emulated channel, EDC input



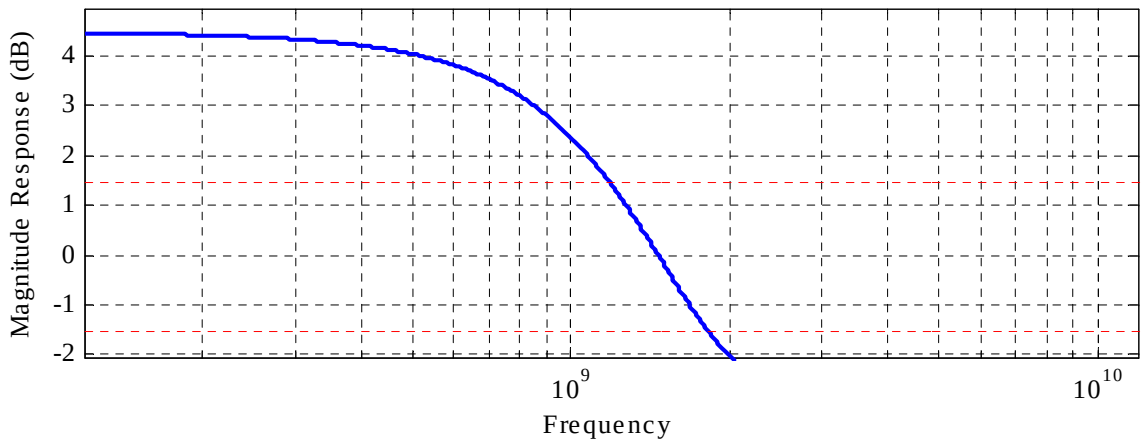
eye diagram at 3.125 Gb/s

Input eye for LX-4. TDP higher than Budget?

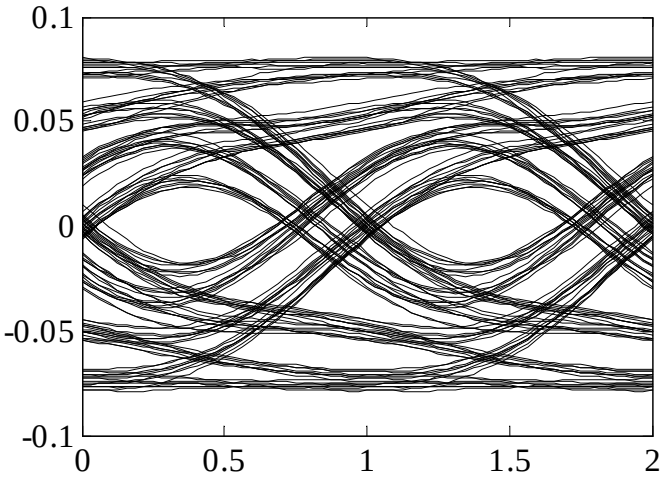
Cambridge-Model Fiber #1 (f18017)
Reach: 300m



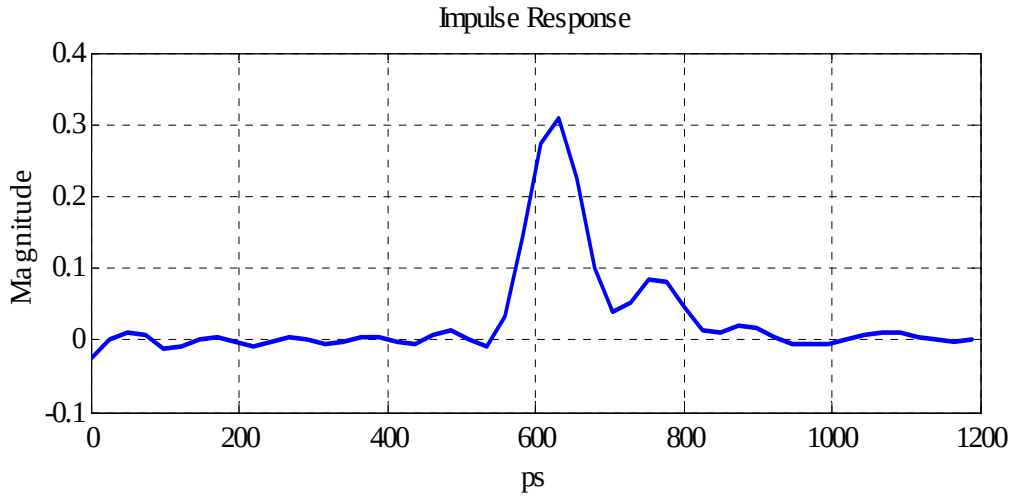
BandWidth (3dB) =1.19GHz BandWidth (6dB) =1.83GHz Roll-Off (3dB) =3.96dB/Octave

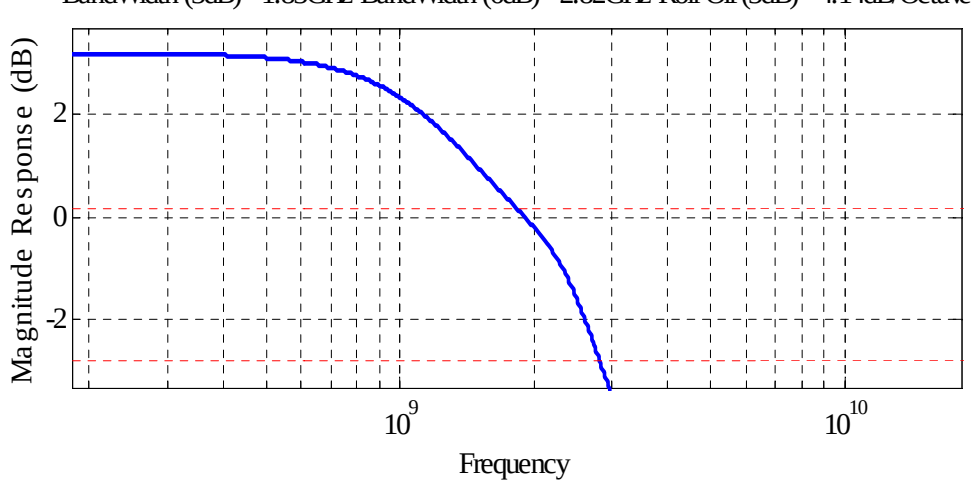


Cambridge-Model Fiber #1 (f18017), scaled to 220 meter

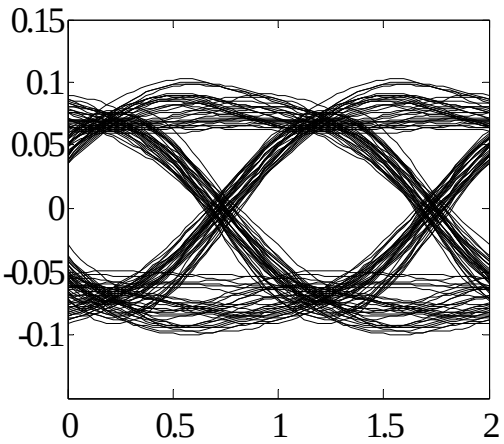


EDC input



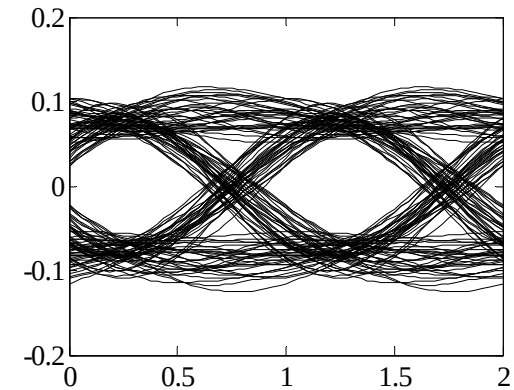


EDC Performance with Cambridge-Model Fiber #1 : f18o17



- **Reach: 220m**
- **Equalized output: SNR@10^{-11} BER = 25.5 dBe**
- **SNR@10^{-11} BER (PIE-D) = 16.6 dBe + 6.1 dBe = 22.7 dBe**

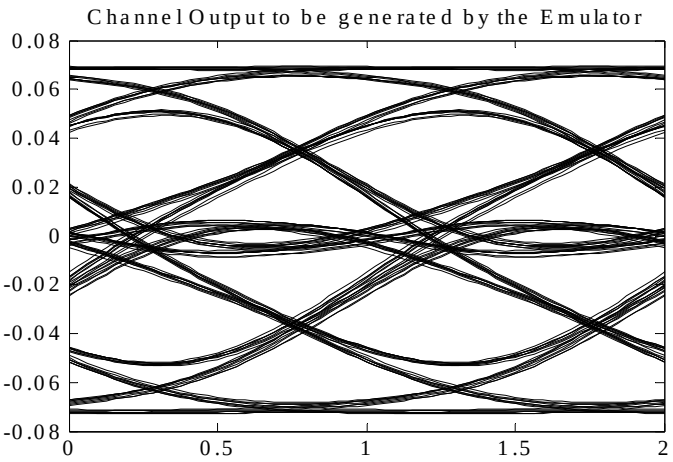
Pre-slicer, equalized waveform



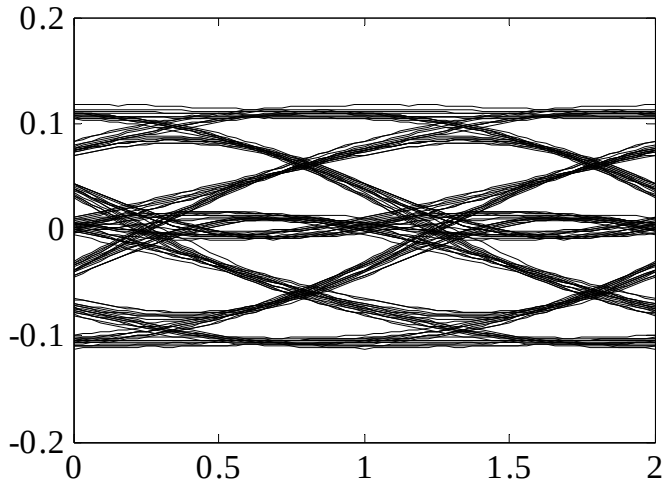
- **Reach: 300m**
- **Equalized output: SNR@10^{-11} BER = 29 dBe**
- **SNR@10^{-11} BER (PIE-D) = 16.6 dBe + 8.6 dBe = 25.2 dBe**

Pre-slicer, equalized waveform

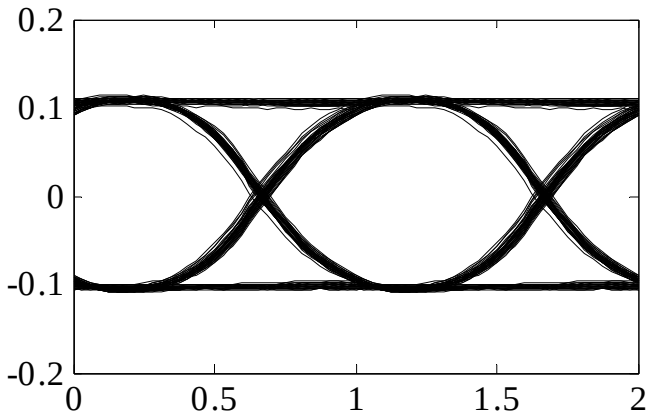
Cambridge-Model Fiber #2 (f42o20): Reach 300m



original channel

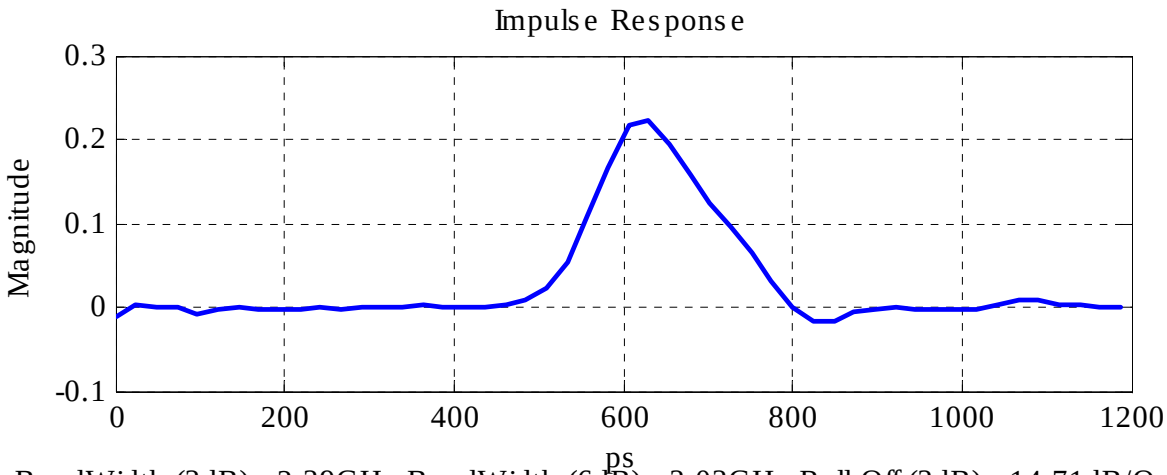


emulated channel

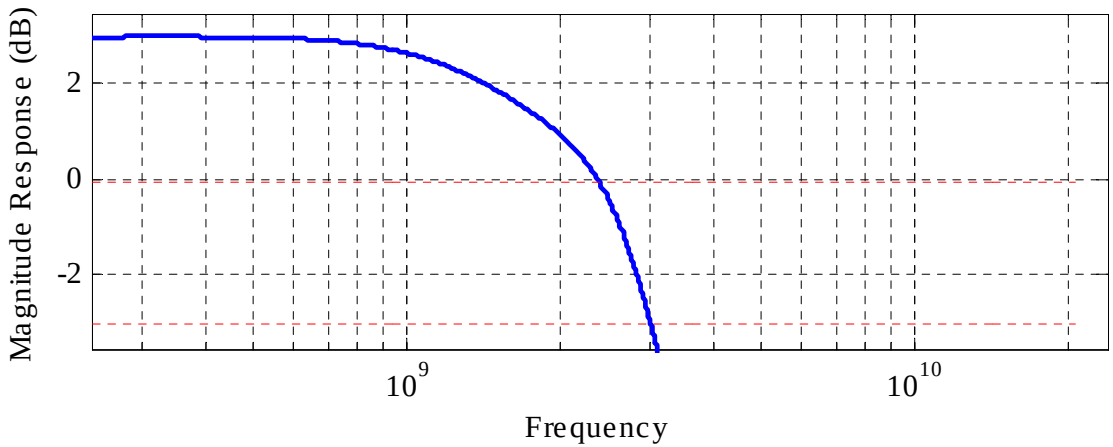


eye diagram at 3.125 Gb/s

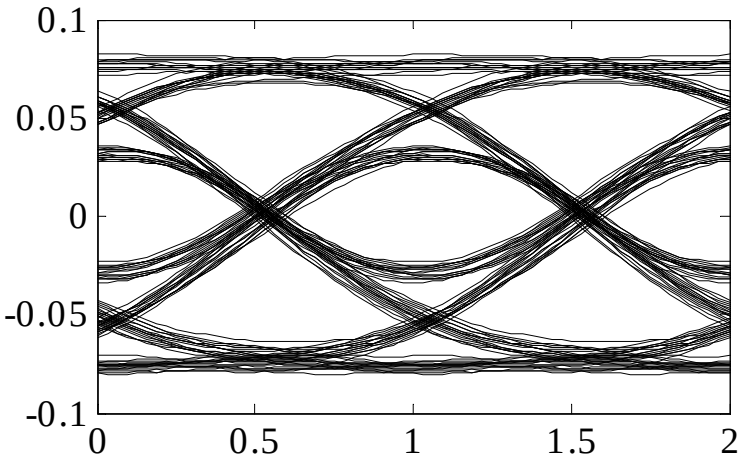
Cambridge-Model Fiber #2 (f42o20)
Reach: 300m



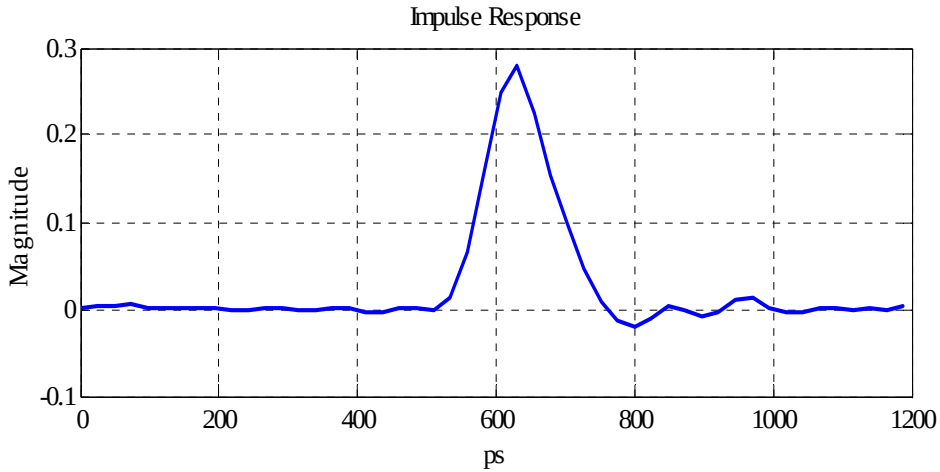
BandWidth (3dB) =2.39GHz BandWidth (6dB) =3.03GHz Roll-Off (3dB) =14.71dB/Octave

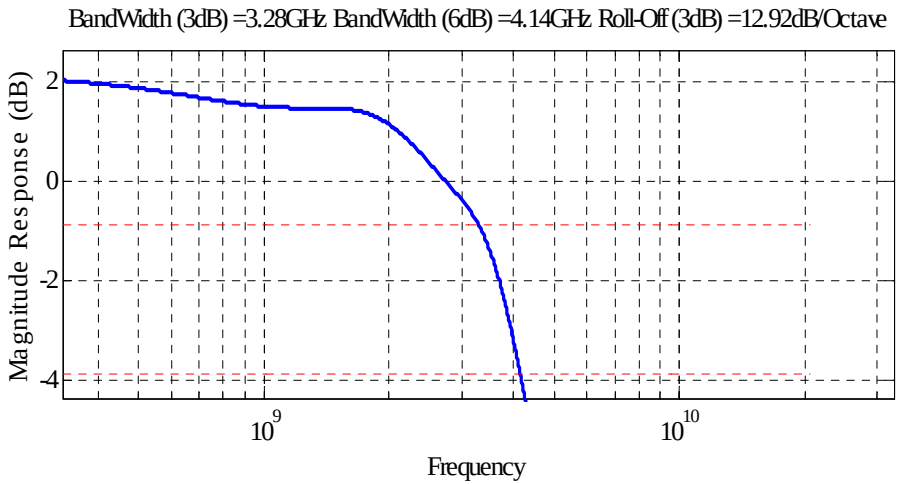


Cambridge-Model Fiber #2 (f42o20), scaled to 220 meter

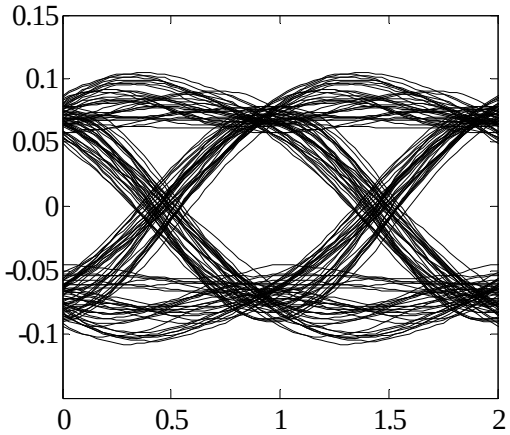


EDC input



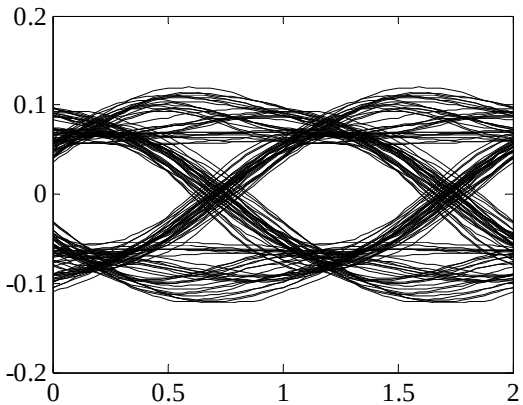


EDC Performance with Cambridge-Model Fiber # 2 (f42o20)



- **Reach: 220m**
- **Equalized output: SNR@10^{-11} BER = 22.1 dBe**
- **SNR@10^{-11} BER (PIE-D) = 16.6 dBe + 5.0 dBe = 21.6 dBe**

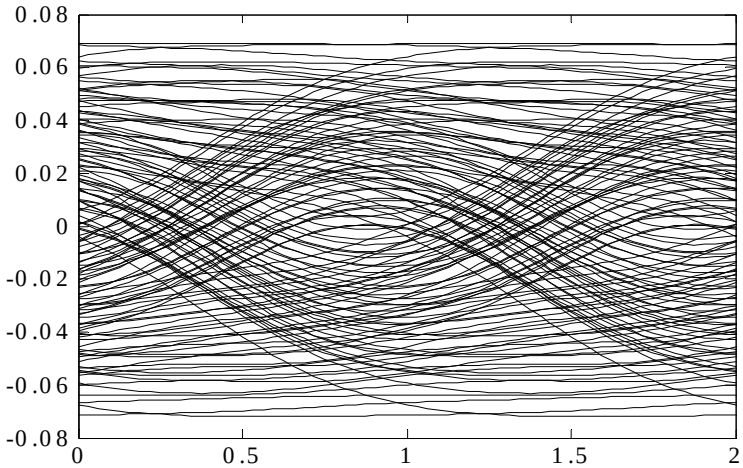
Pre-slicer, equalized waveform



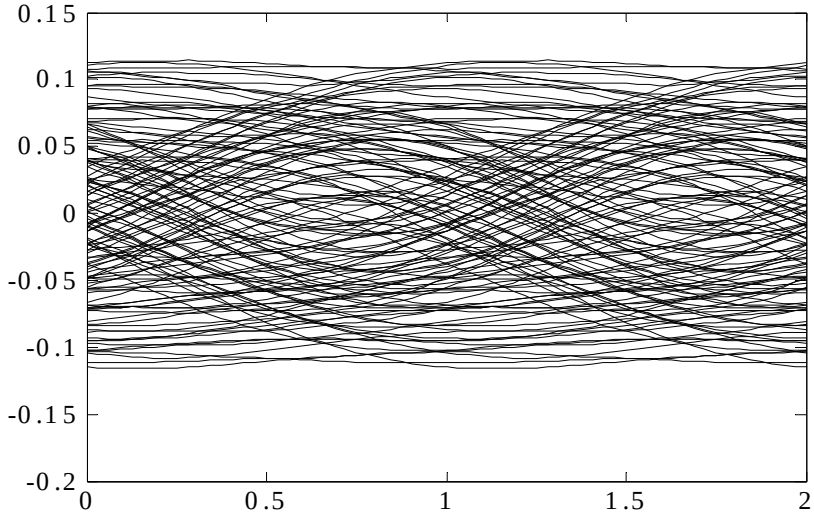
- **Reach: 300m**
- **Equalized output: SNR@10^{-11} BER = 25.9 dBe**
- **SNR@10^{-11} BER (PIE-D) = 16.6 dBe + 8.4 dBe = 25 dBe**

Pre-slicer, equalized waveform

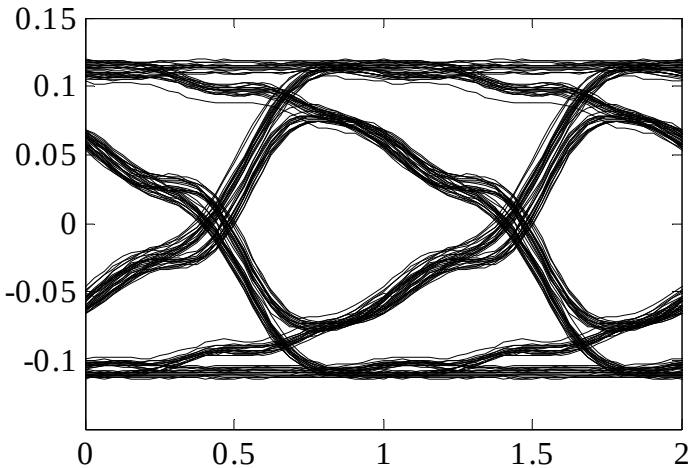
Cambridge-Model Fiber #3 (f48o17); Reach: 300m



original channel



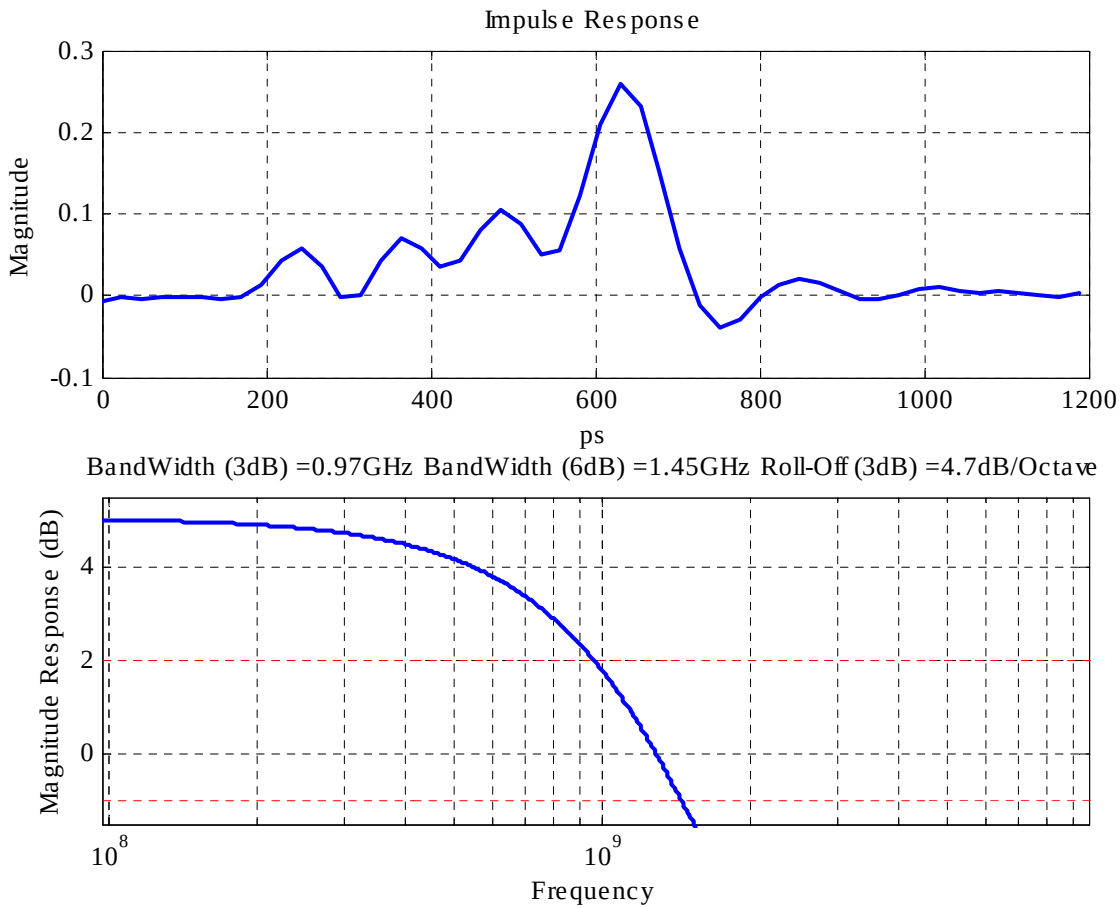
emulated channel



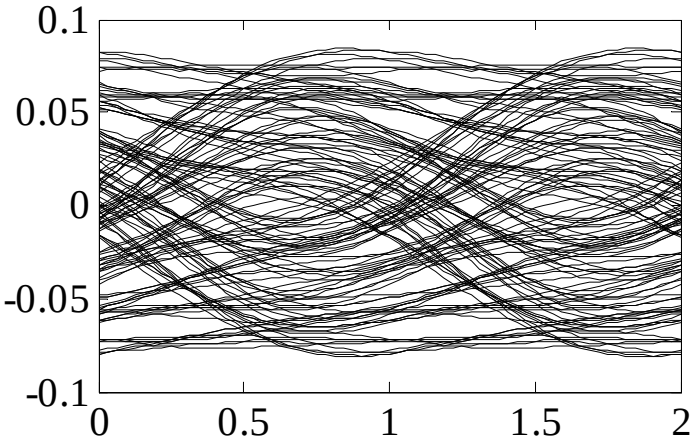
eye diagram at 3.125 Gb/s

Input eye for LX-4.
TDP higher than
Budget?

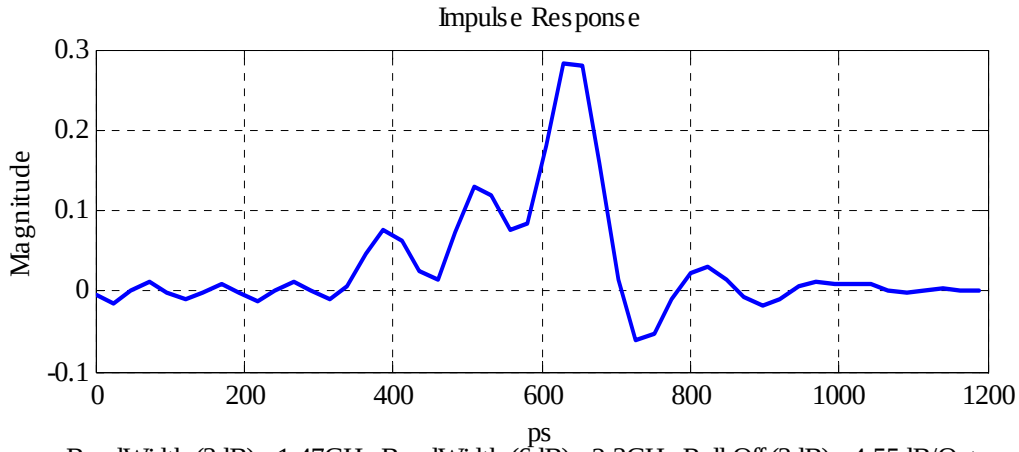
Cambridge-Model Fiber #3 (f48o17)
Reach: 300m

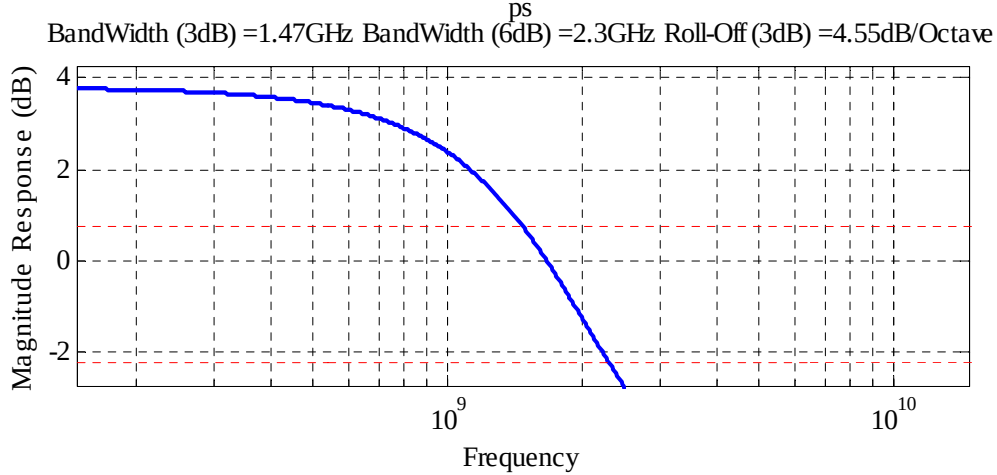


Cambridge-Model Fiber #3 (f48o17), scaled to 220 meter

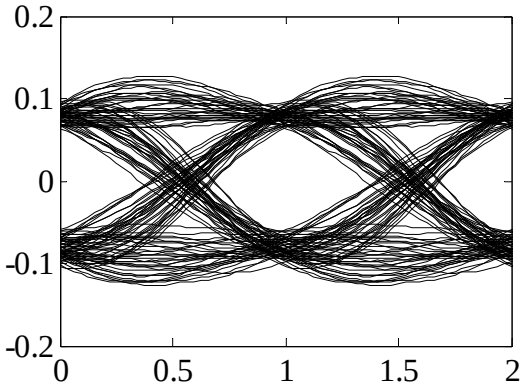


EDC input





EDC Performance with Cambridge-Model Fiber # 3 (f48o17)

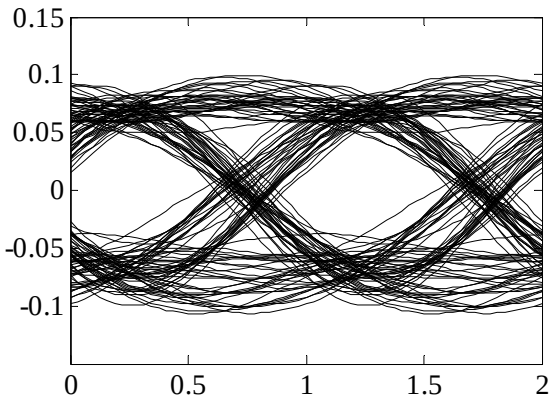


Reach: 220m

Equalized output: SNR@10^{-11} BER = 25.3 dBe

SNR@10^{-11} BER (PIE-D) = 16.6 dBe + 6.8 dBe = 23.4 dBe

Pre-slicer, equalized waveform



Reach: 300m

Equalized output: SNR@10^{-11} BER = 29.5 dBe

SNR@10^{-11} BER (PIE-D) = 16.6 dBe + 8.4 dBe = 25 dBe

Discussions

- **Even for worst-case channels, a well designed, fully adaptive EDC can achieve 300m within 6-7 (optical) dB total dispersion penalty (the penalty with typical links will be < 5dBo)**
- **The penalty enhancement, viz. increment in PIE-D + implementation (including adaptation) penalty, can be controlled to be ~4dB across quasi-symmetric, precursor and postcursor channels.**
- **For precursor channels, increase in PIE-D may be benign but implementation penalty can increase more significantly**
  - **More complexity of "front-end filtering" such as Whitened matched filter**
- **For quasi-symmetric channels, the implementation penalty can be controlled to not significantly increase from 220m to 300m**
  - **Increase in PIE-D more significant**
- **For post-cursor channels, the implementation penalty and PIE-D tend to increase more uniformly.**

Discussions (Cont'd)

- **Precursor channel tend to stress EDC implementation most, so recommend compliance test to include only precursor channel or at maximum, include post-cursor channel as well.**
- **Further improvements in ROSA sensitivity, transmit launch schemes, etc will improve feasibility margin of 10GBASE-LRM at 300m.**
- **Connectors not included within the channel model; this could degrade performance (to be determined).**
- **Further relaxing optics specs might also allow for feasible link at 300m but was not considered.**

Conclusions

- **Experimental data with fully adaptive EDC demonstrating robust performance at up to *300m* for 3 representative worst-case Cambridge MMF provided and studied**
  - **Even for such challenging links, at 300m, power penalty < 7dB.**
  - **Significant margin at 220m.**
  - **Qualitative arguments on reach v/s implementation and total penalty for different classes of channels.**
- **Suggested that while 10GBASE-LRM continues effort with distance objective of 220m, it should be noted that 10GBASE-LRM can hit a high percentage of links at 300m.**