Simulations of 100G-SR4 Link

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IEEE 802.3 100GNGOPTX Study Group

Newport Beach

Overview

- **100G-SR4 link performance is dominated by the VCSEL response**
  - For this reason we start with spatial rate equation model of VCSEL in time time domain to study the link
  - Investigated 1-150 m OM3 fiber referred to as “Linear Fiber” which assumes simple 2000 MHz.km BW
  - Also investigated 1-150 m OM3 fiber based on index profile referred to as “Pre-cursor Fiber” and “Split Fiber”
- **An accurate link model is needed to investigate if a moderate size equalizer can extend link distance to 100 m on OM3 or 150 m on OM3 and possibly unretimed**
  - The alternative would be to cut link distance to about half and assume simple slicer
- **Due to computational time required single spatial connector and spatial fiber were modeled.**
- **Updated simulations from Nov-11**
  - Paloc=5 dBo
  - Adjusted DMD of spatial fiber to be ~0.32 ps/m now the result matches with linear fiber model.

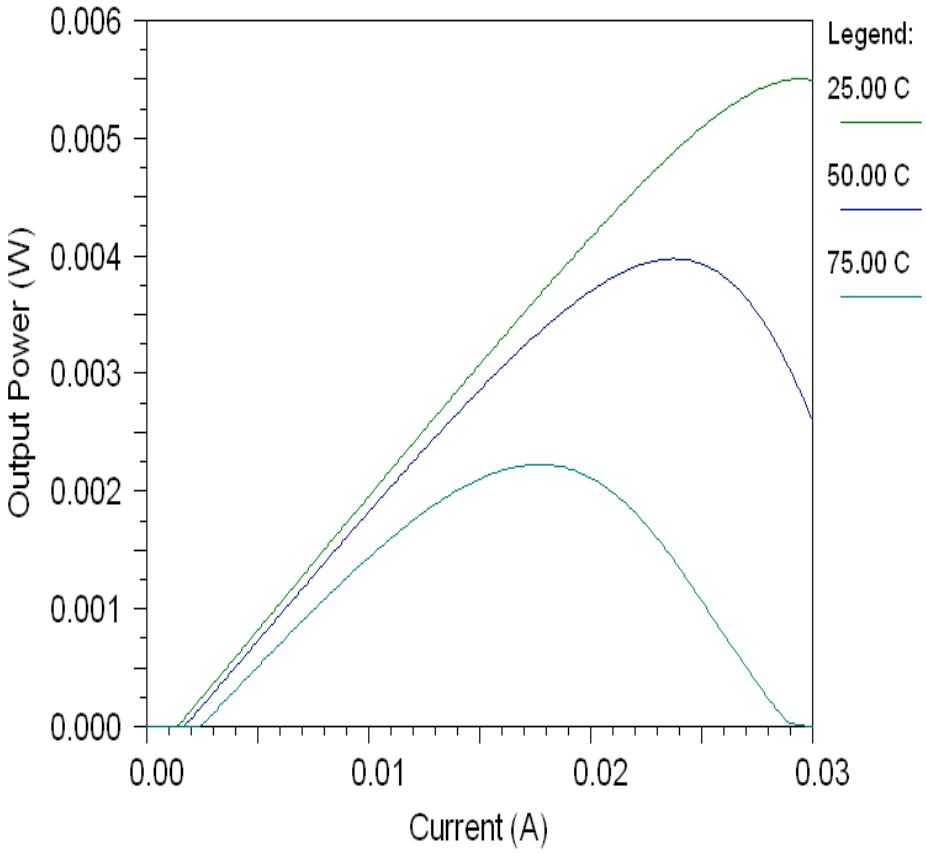
Authors would like to thank Paul Kolesar, Robert Lingle, Kasyapa Balemarthy, Jonathan King, and David Cunningham for their valuable inputs.

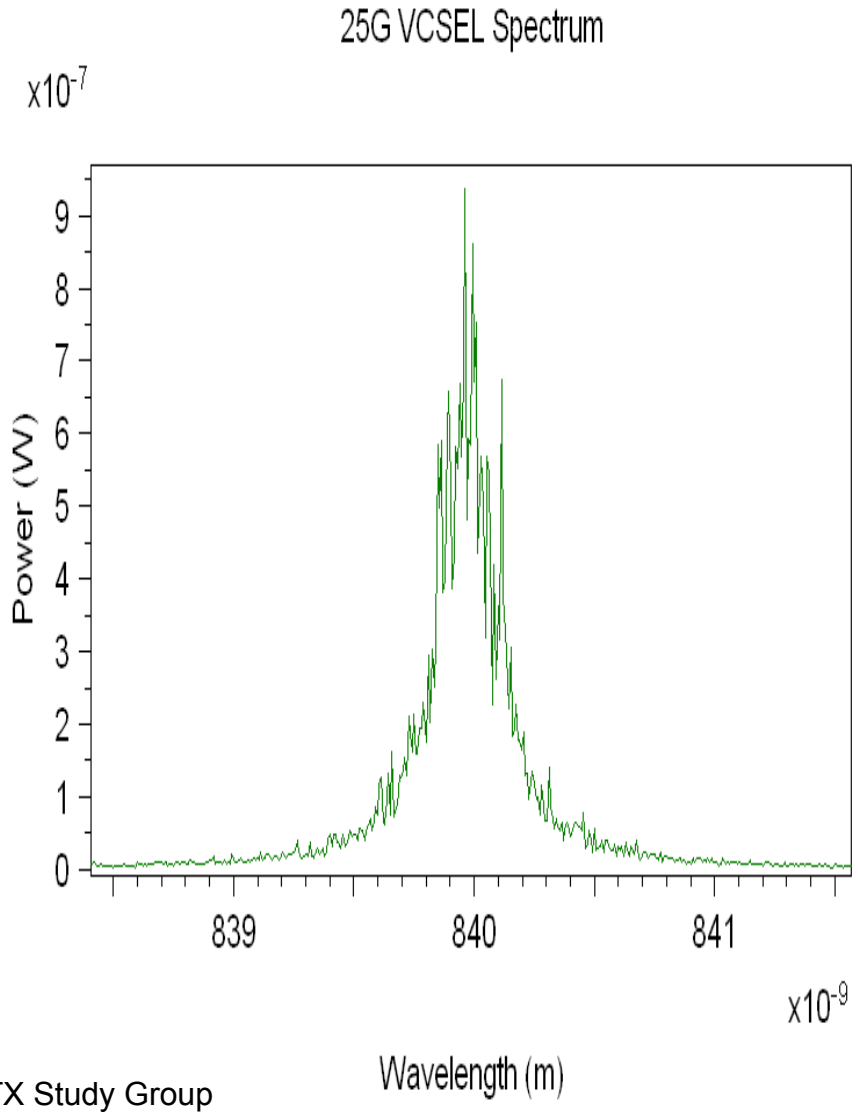
VCSEL and Link Model

- **Simulation environment RSOFT**
- **Transmitter parameters**
  - VCSEL model based on spatial rate equation optimized for 25.78 GBd Center wave length=840 nm
  - Spectral width = 0.6 nm
  - VCSEL RIN = -129 dB/Hz
  - Mode size 7.5 um and offset launched by 7.5 um
  - 4 ps p-p PJ was added to the electrical driver
  - ER ~ 6 dB
  - Operating Temp=25 C
  - Direct measurement of pulse $Tr_{10\text{-}90\%}$=20 ps, $Tf_{10\text{-}90\%}$=44 ps, $Tr_{20\text{-}80\%}$=14 ps, $Tf_{20\text{-}80\%}$=22 ps
- **Receiver Parameters**
  - Receiver BW=0.6*25.78 GBd
  - Receiver Sensitivity with Ideal Optical Signal=-7 dBm AOP
  - PD responsivity 0.45 A/W
  - TIA gain 1 kΩ
- **Fiber /link Parameters**
  - S0=0.10275 ps/nm^2.km, λ0=1316 nm
  - Linear fiber model assumes fiber BW=2000 MHz.Km, fiber loss 3.5 dB/Km
  - Spatial fiber model assumes Peak Index=1.46, Delta=1%, alpha=2.09
    - 20 primary modes where propagated in the case of spatial fiber
  - Connector loss = 1 dB

VCSEL LI and Spectrum

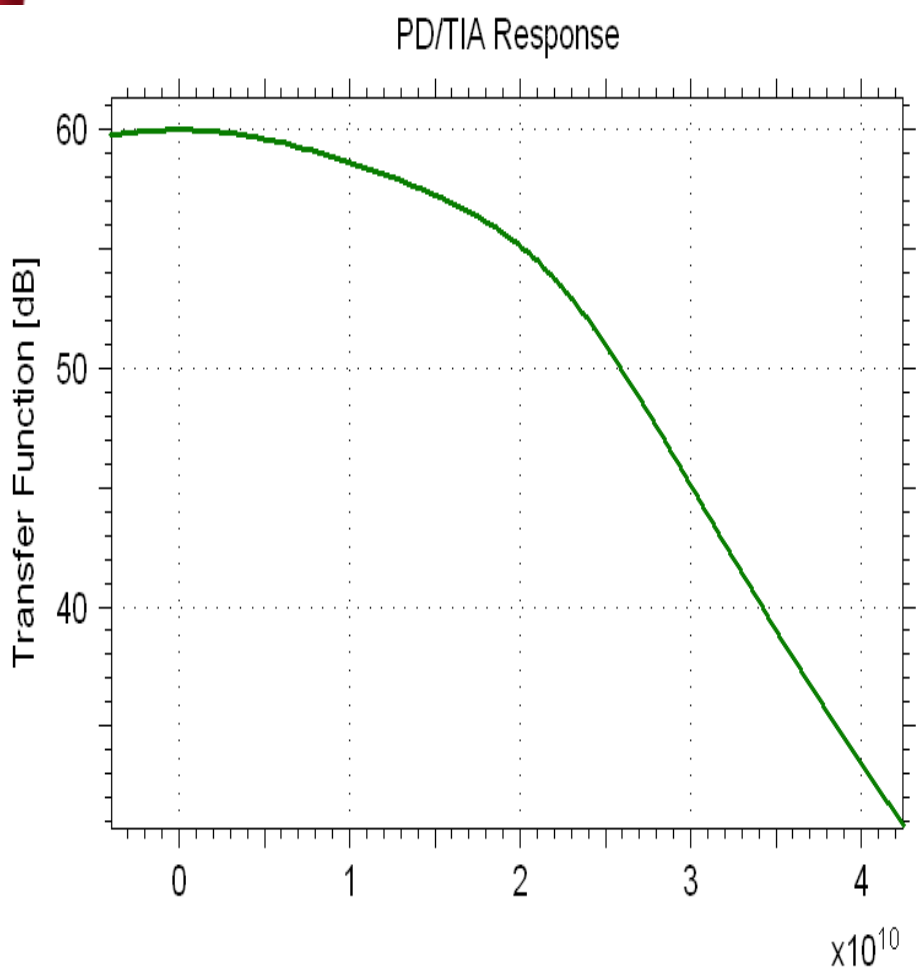
- **Model include thermal effects**
  - Spectral width was further expanded by optical phase noise to get FWHM=0.6 nm

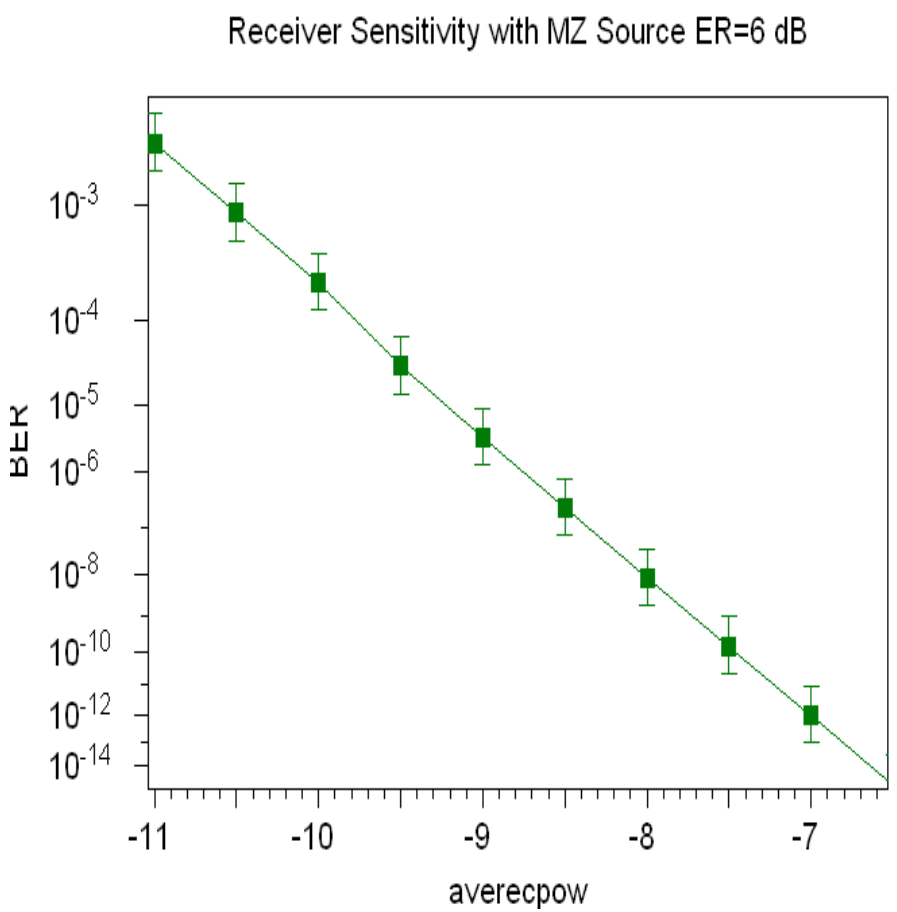




PIN/TIA

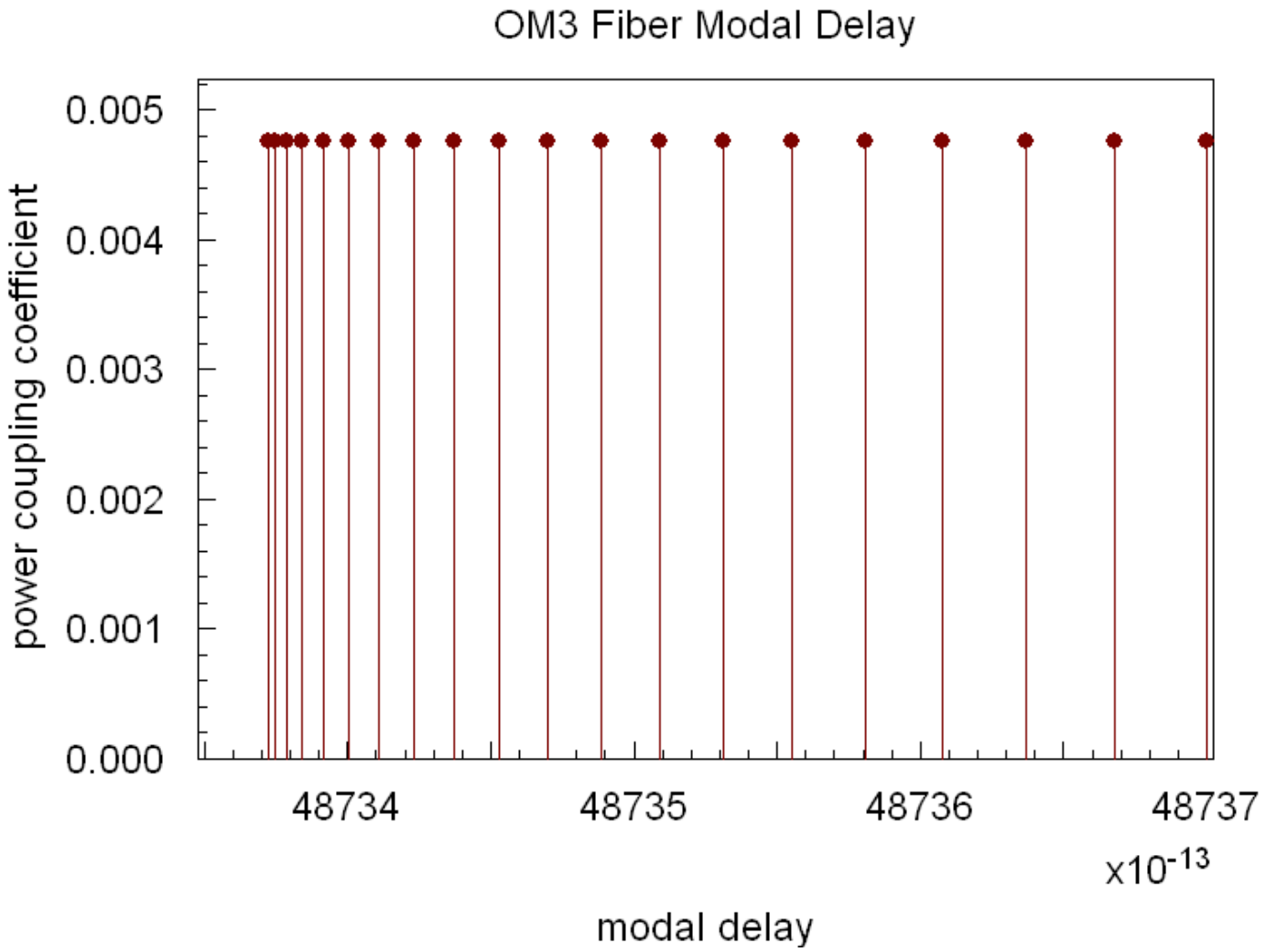
- TIA has TZ=1 kΩ, with BW of 15.75 GHz and sensitivity of -7 dBm with MZ source with ER=6 dB





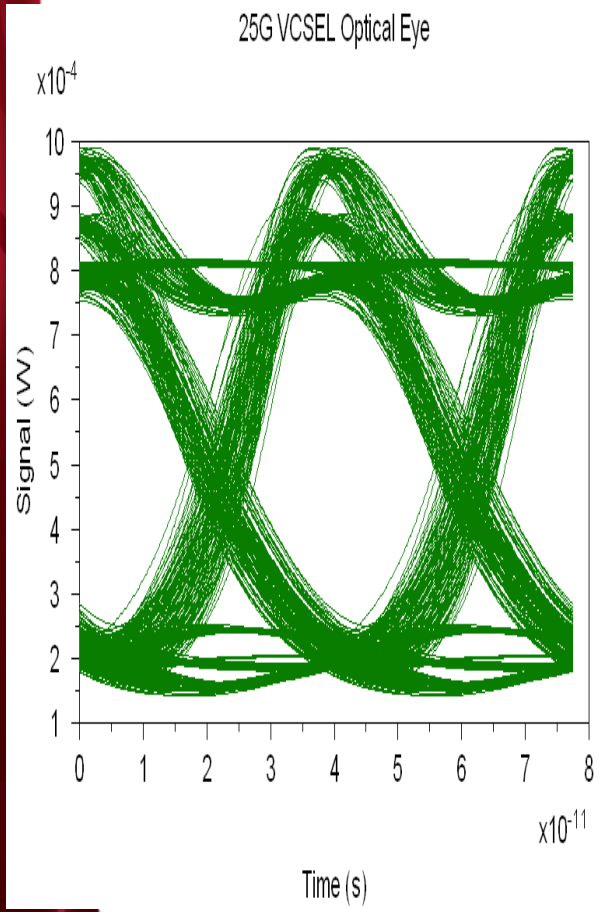
Pre-Cursor Spatial Fiber Mode Delays

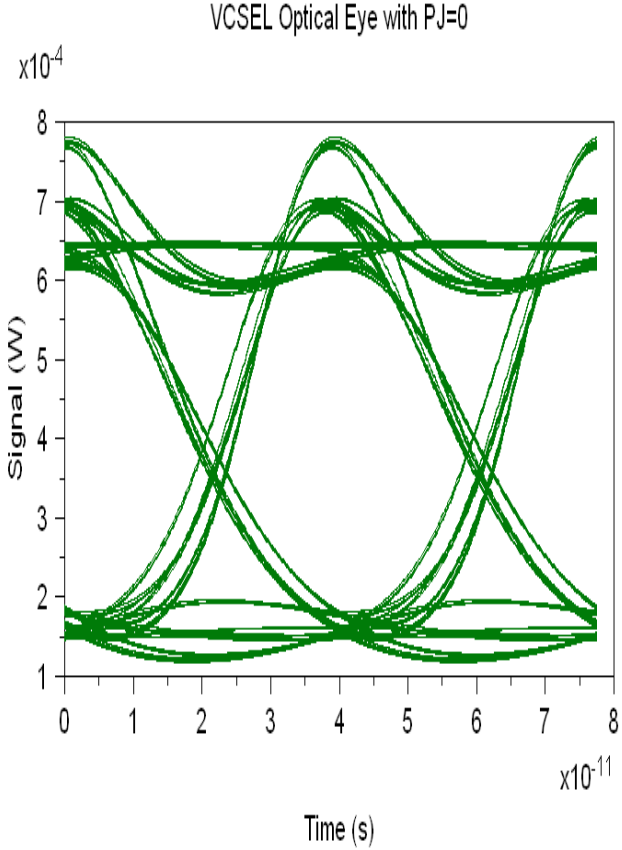
- This fiber has pre-cursor response optimized to have DMD of 0.32 ps/m

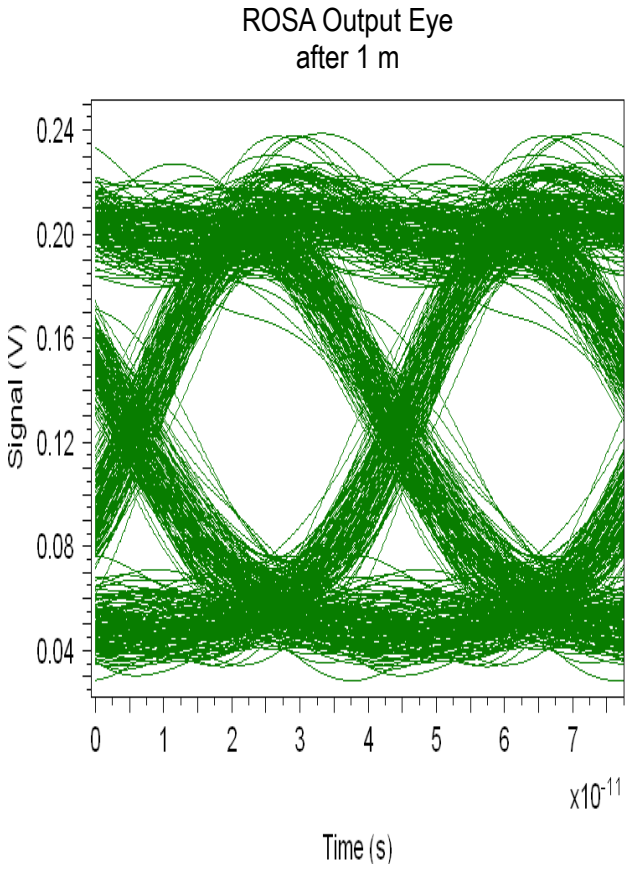


VCSEL Optical Eyes and Back to Back to Back Eye

- **Model based on RSOFT VCSEL spatial rate equation optimized for this application**
  - Left eye optical eye PJ=4 ps, middle eye optical eye PJ=0, right eye electrical B2B PJ=4 ps

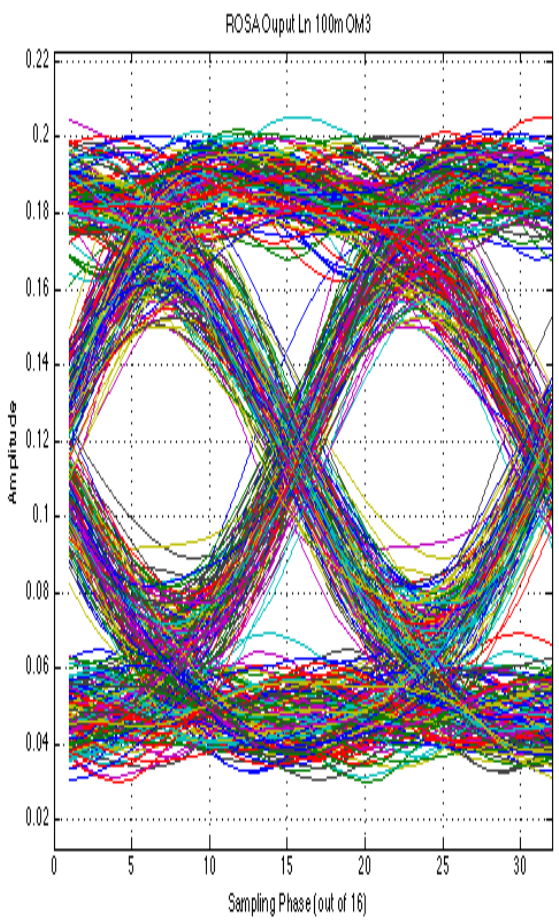


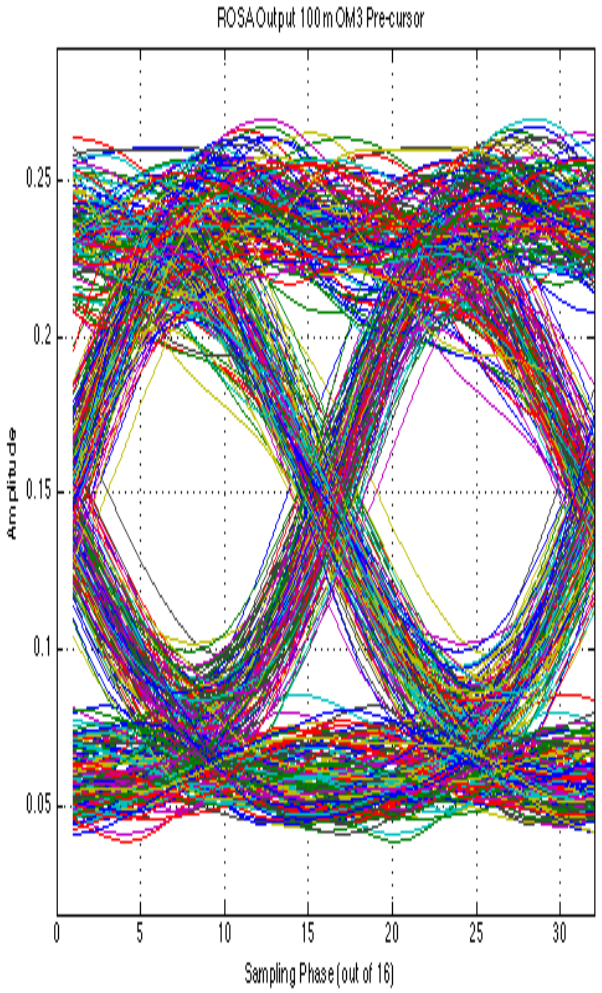


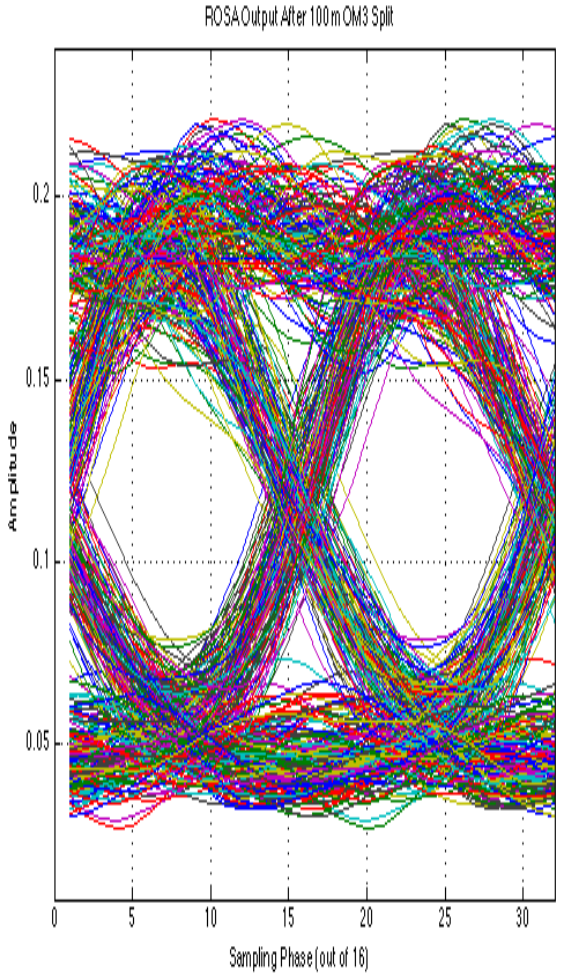


Far End Eye Diagram for 100 m OM3 Fiber

- For linear fiber model (L), pre-cursor (m), split (L) at -3 dBm

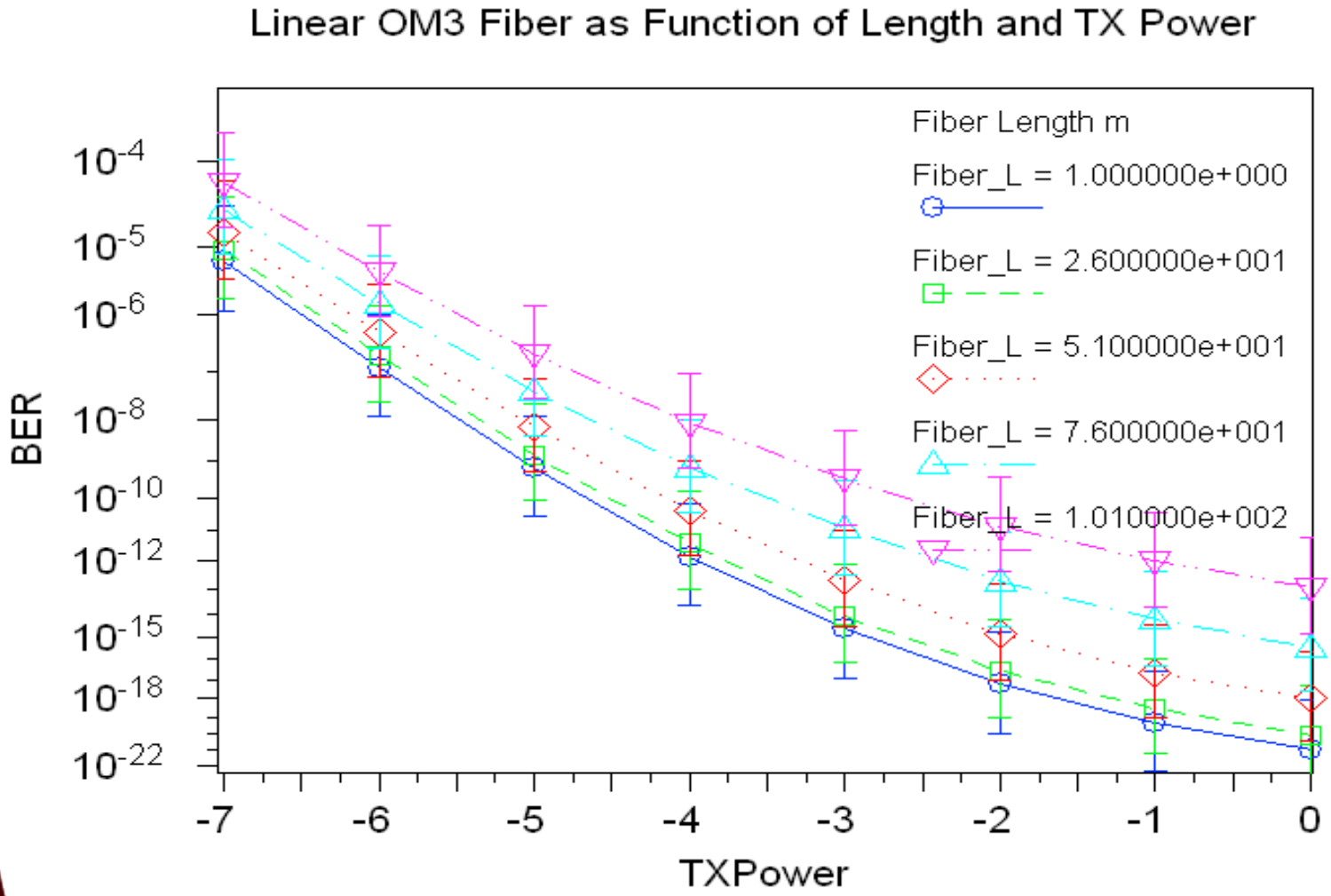






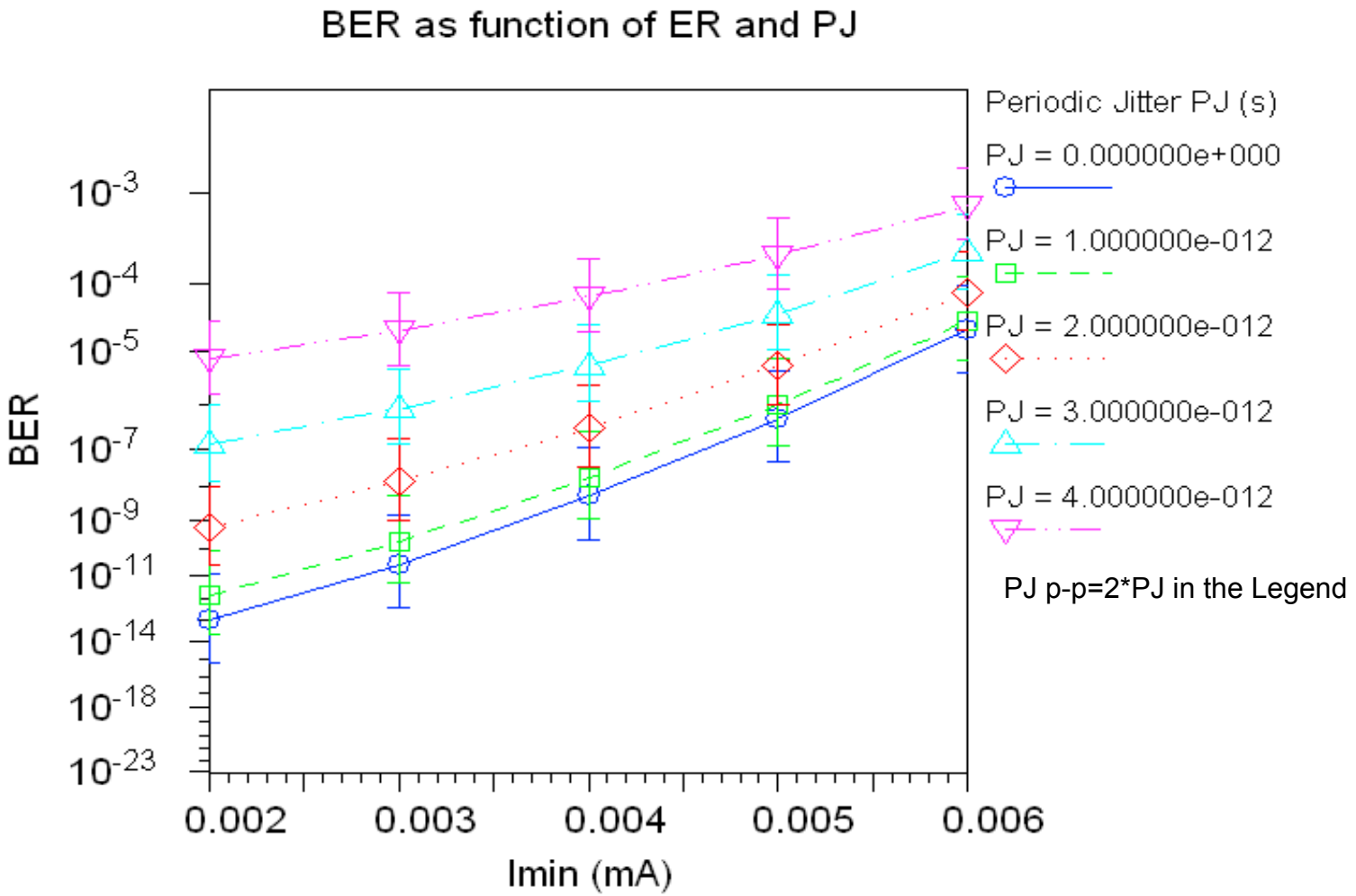
BER Plot for Linear OM3 Fiber Model

- **Fiber reach 1, 26, 51, 76, and 101 m**
  - VCSEL B2B has 2.5 dBo penalty compare to ideal transmitter



Sensitivity as Function of PJ and ER at 100 m and – 3 dBm for Linear Fiber

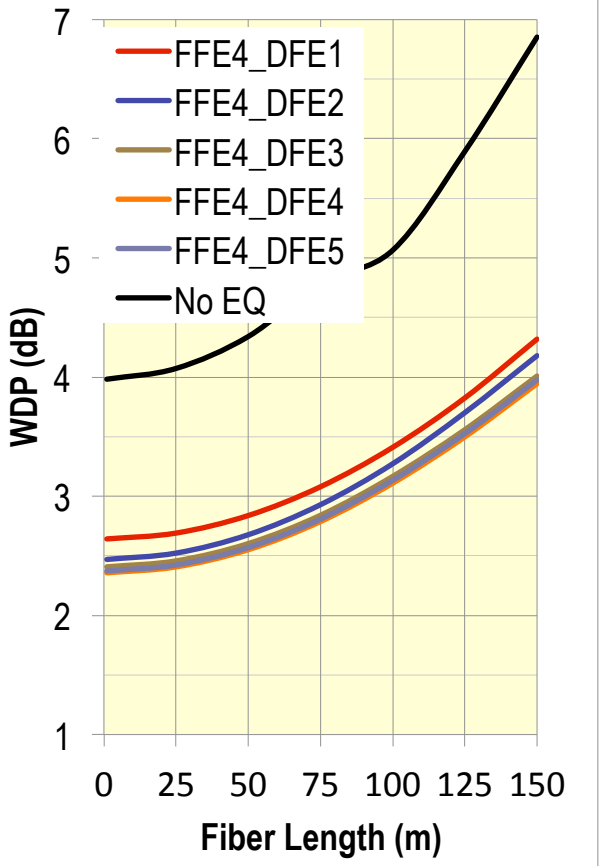
- **PJ was varied from 0-8 ps p-p and Imin was varied from 2 mA (ER=6 dB the default value) to 6 mA (ER=2.7 dB)**
  - It appear that improvement from reducing ER is not sufficient to overcome OMA loss



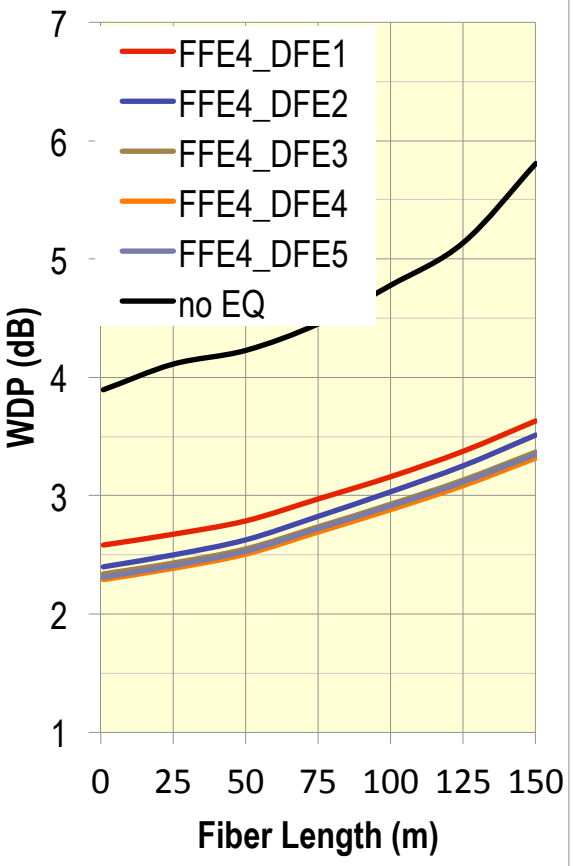
Link Penalty Without Equalizer

- **Penalty calculated with on SFF-8431 xWDP code**
  - Paloc=5 dBo was used instead of LRM 6.5 dBo

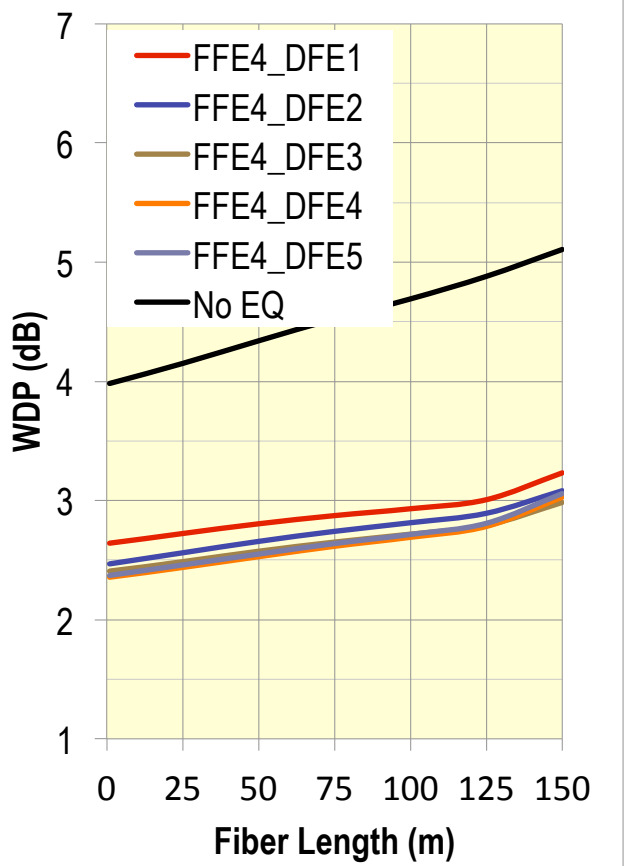
Linear Fiber Model



Pre-Cursor Fiber Model

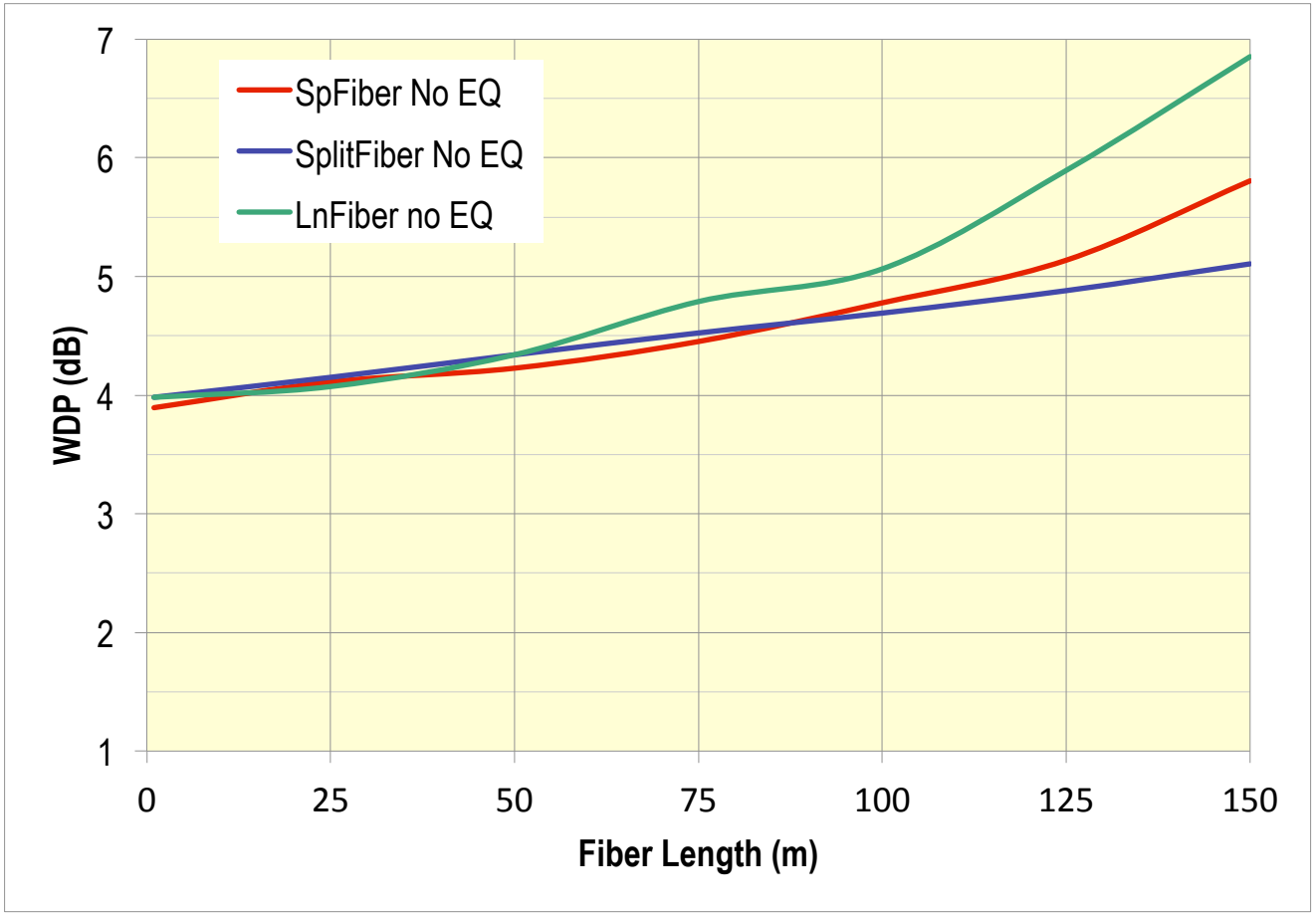


Post-Cursor Fiber Model



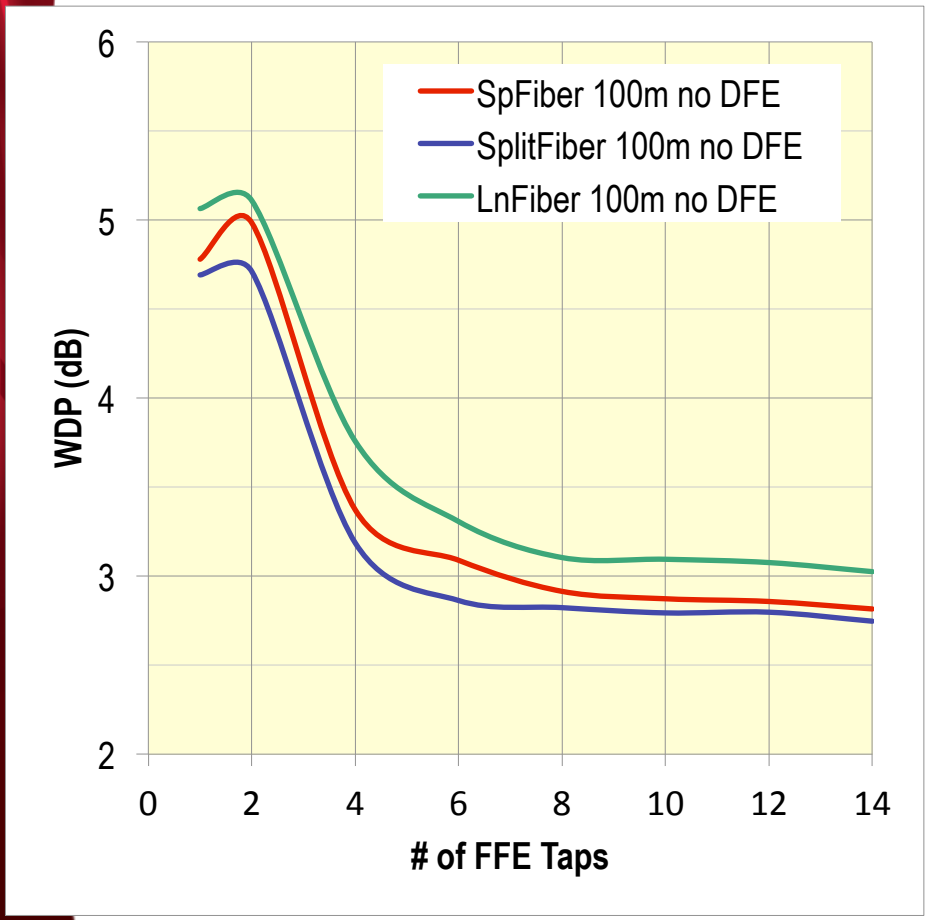
Link Penalty For 3 Fibers Models

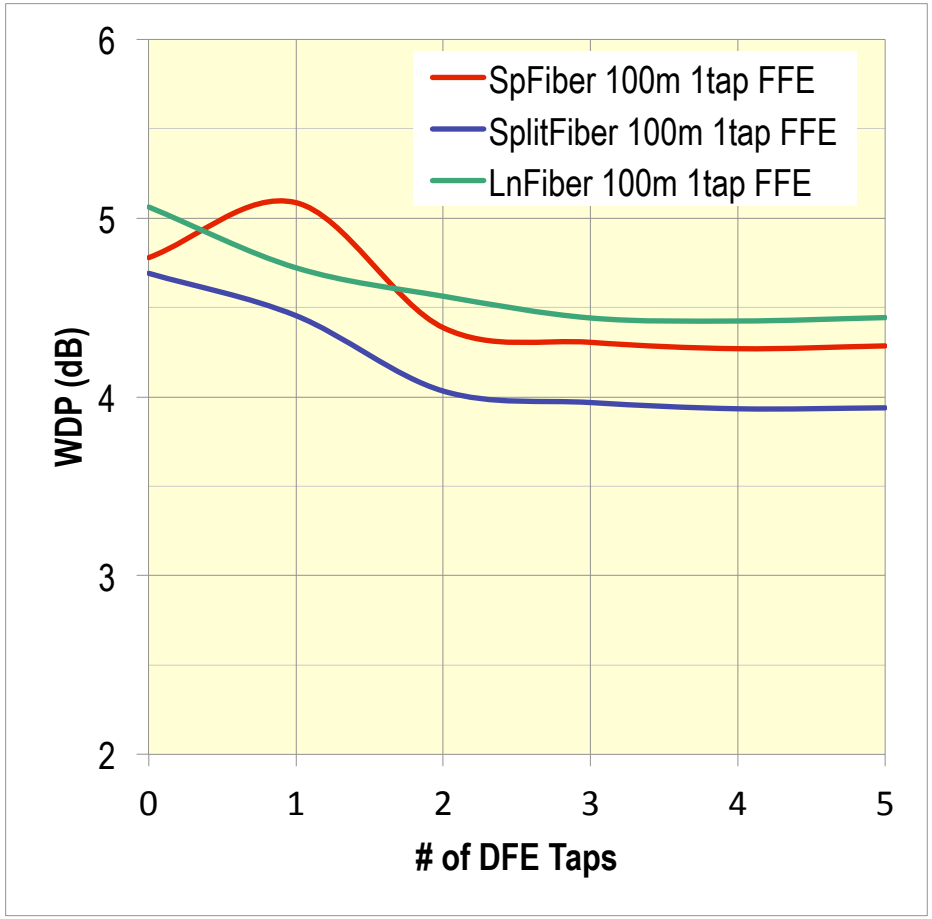
- No EQ penalty



Link Penalty Without FFE or DFE for 100 m Link

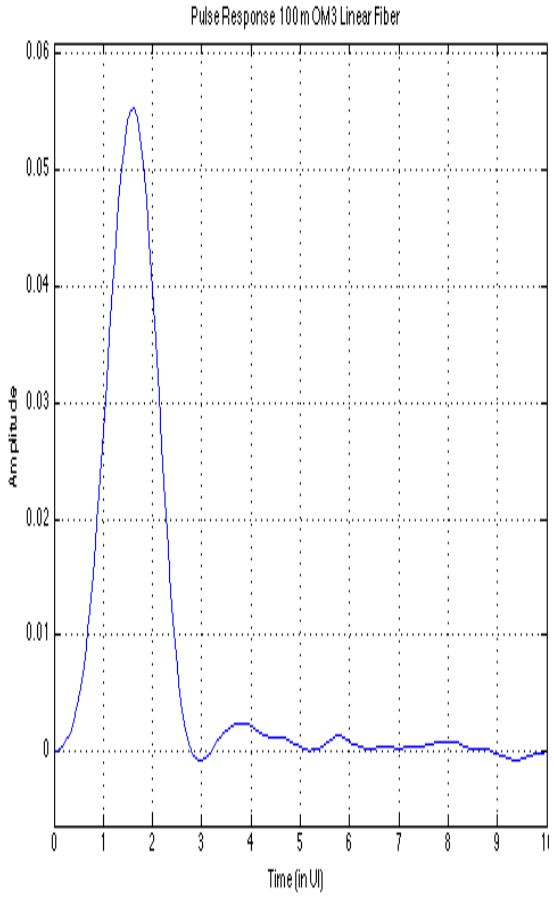
- Link penalty indicate DFE does little for the optical channel

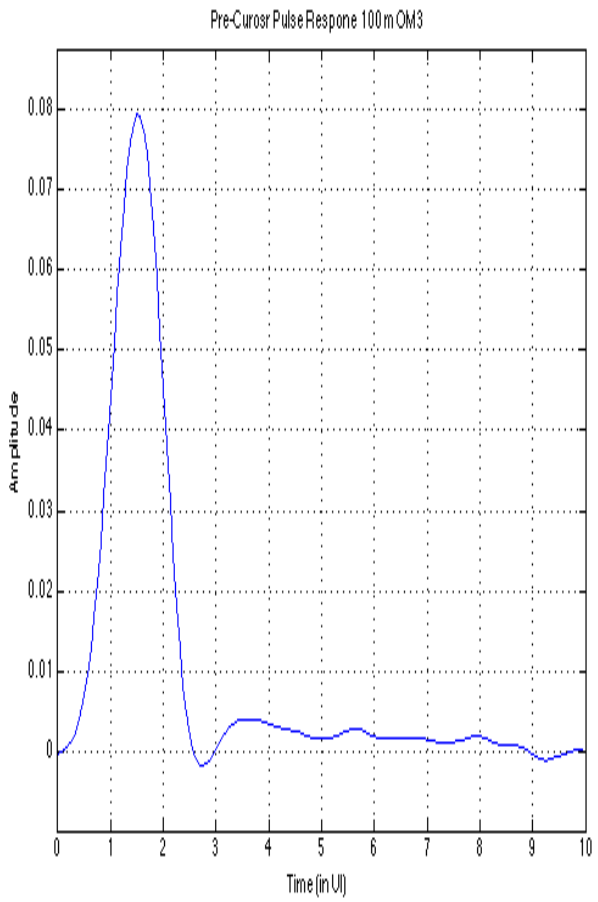


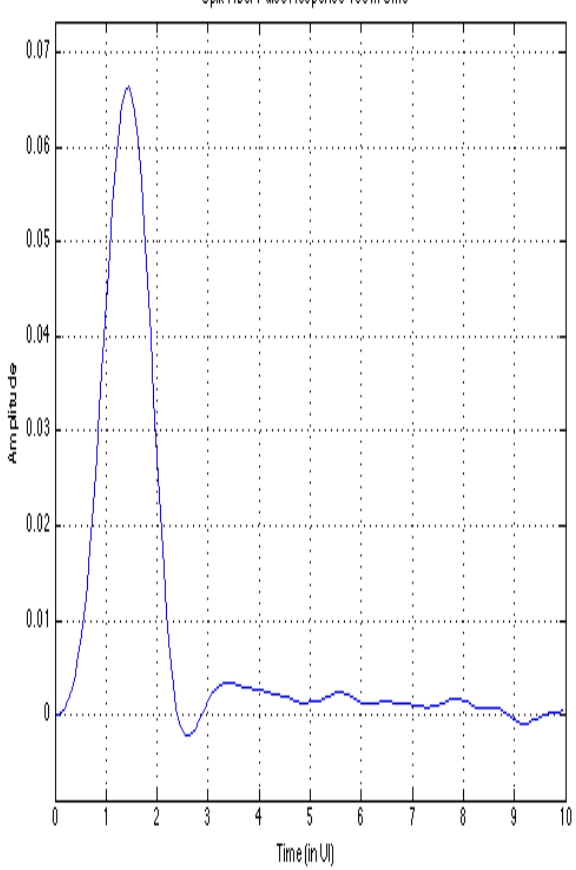


ROSA Output Pulse Response After 100 m of OM3

- For linear fiber model (left), pre-cursor (middle), split (right)

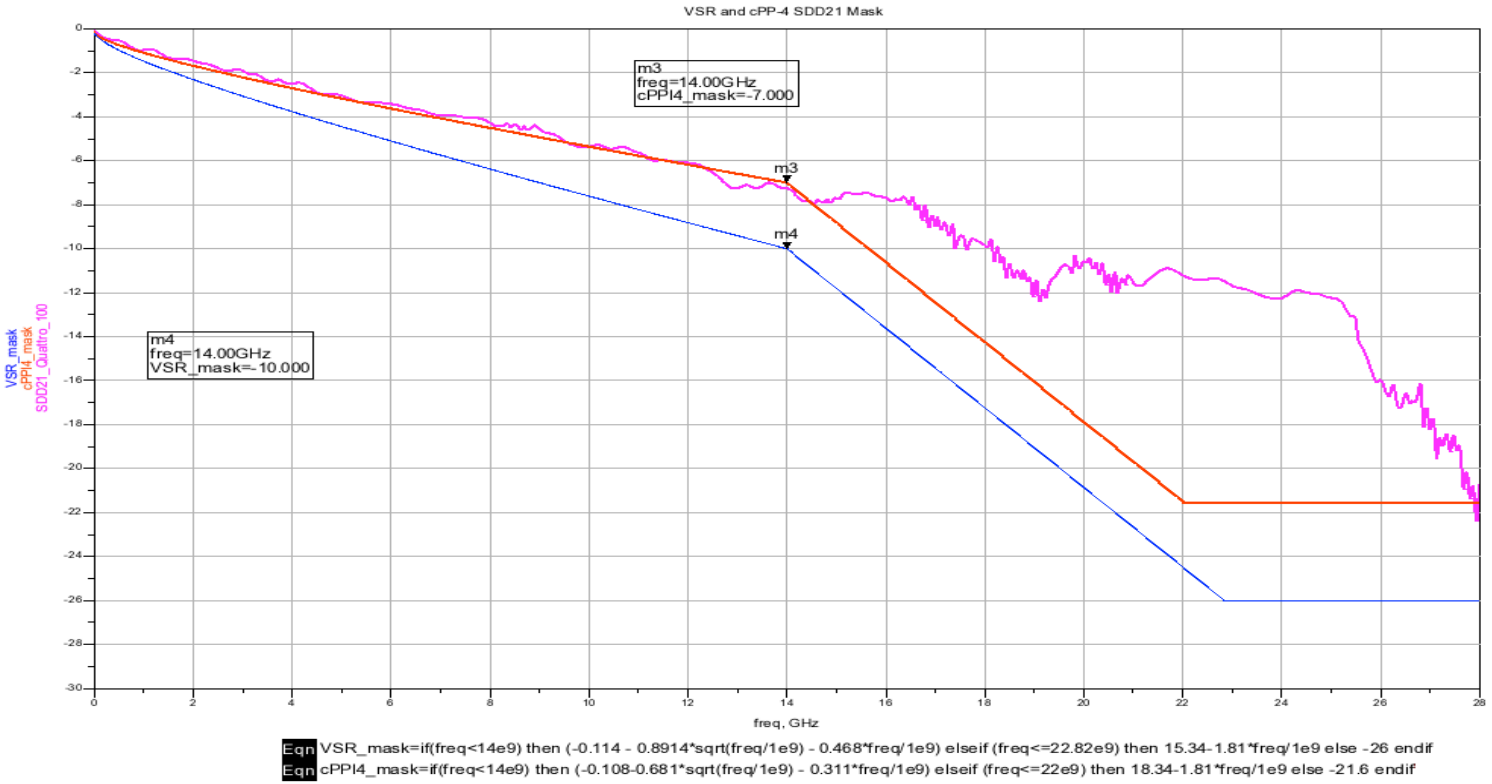


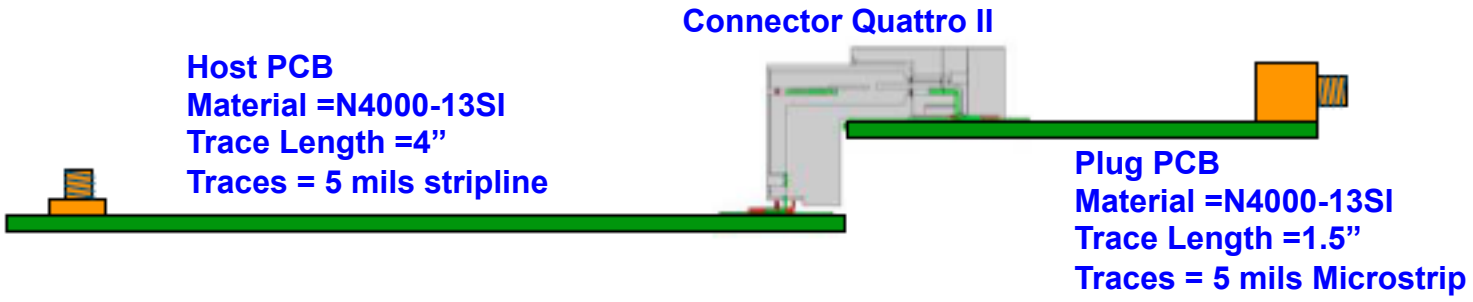




cPPI-4 Channel Based on TE Quattro II

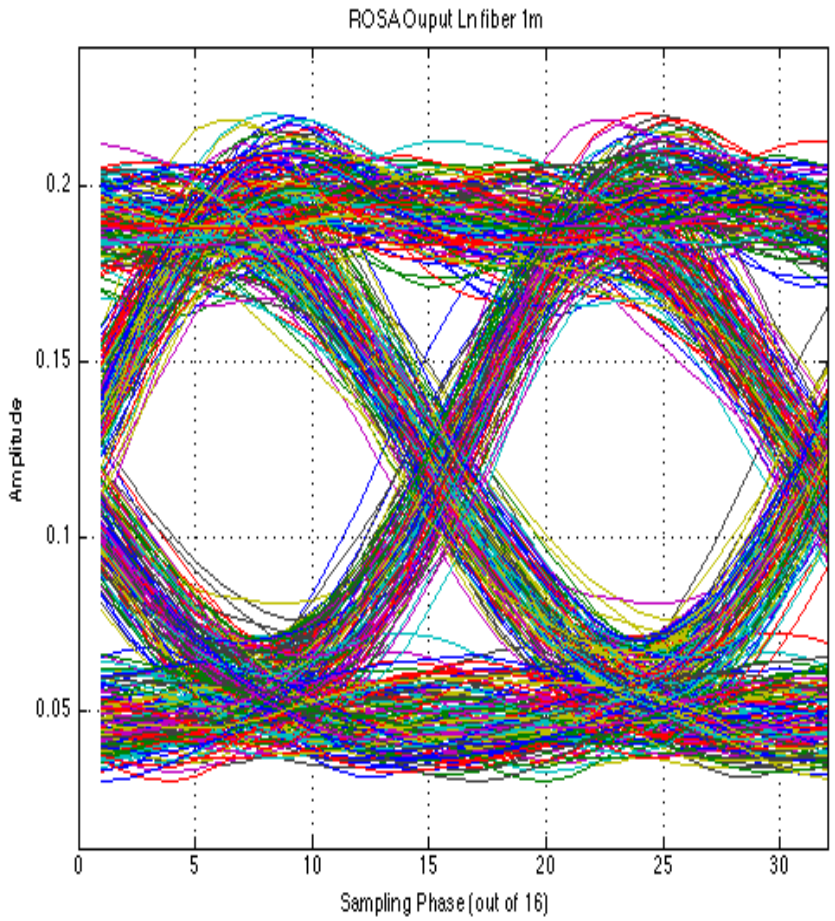
- VSR mask also shown

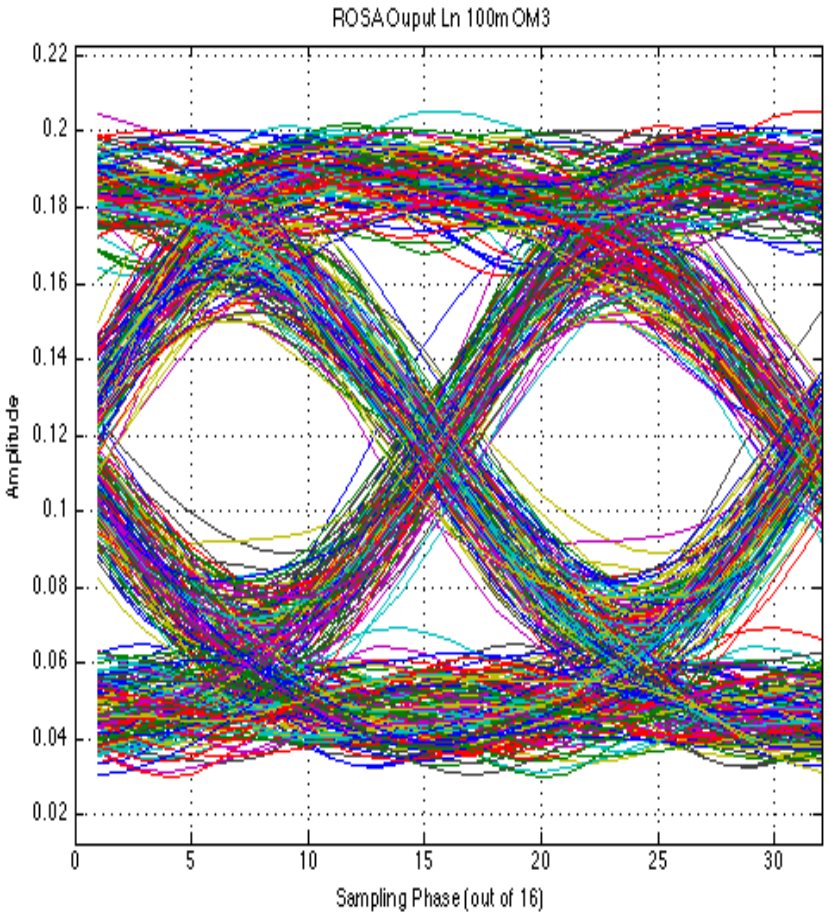




ROSA Output Linear Fiber Model

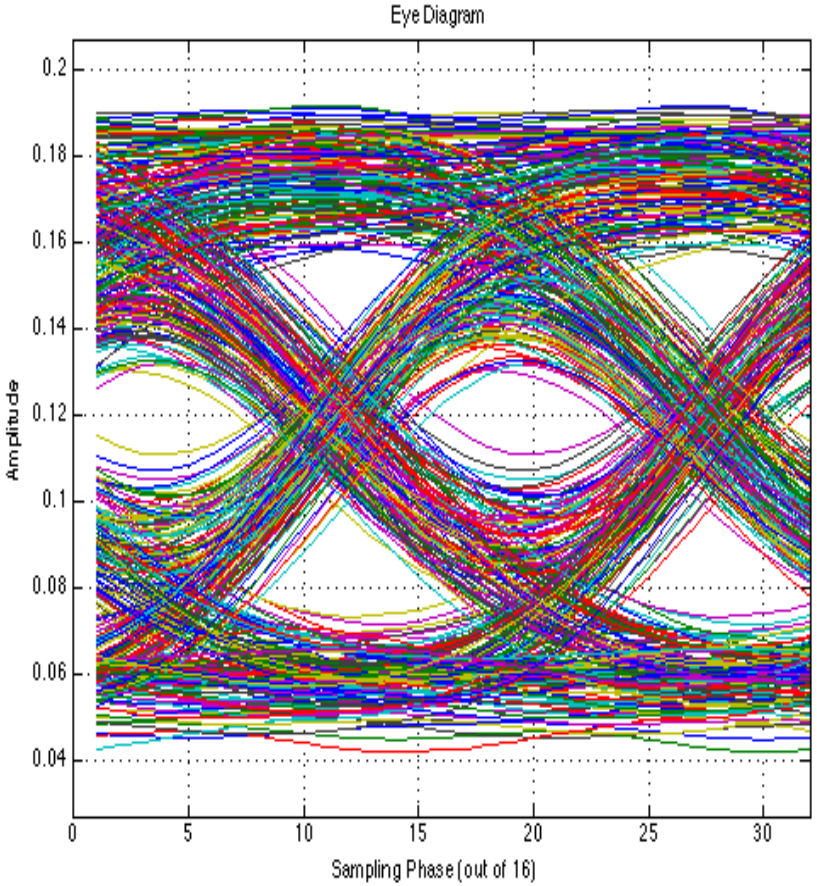
- After 1 m and 100 m of OM3 fiber

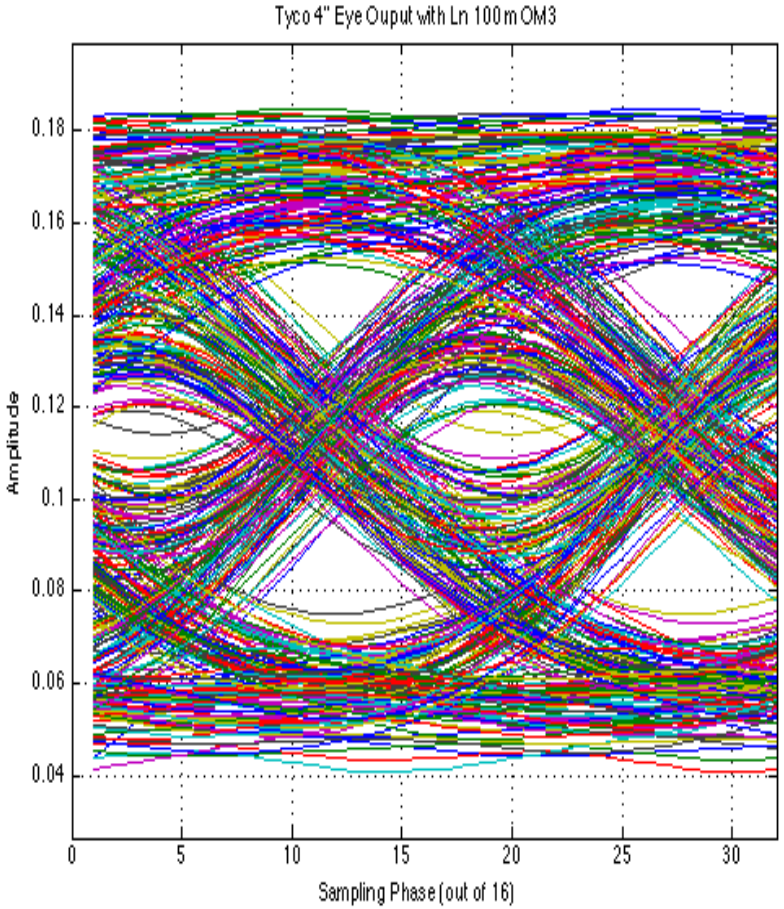




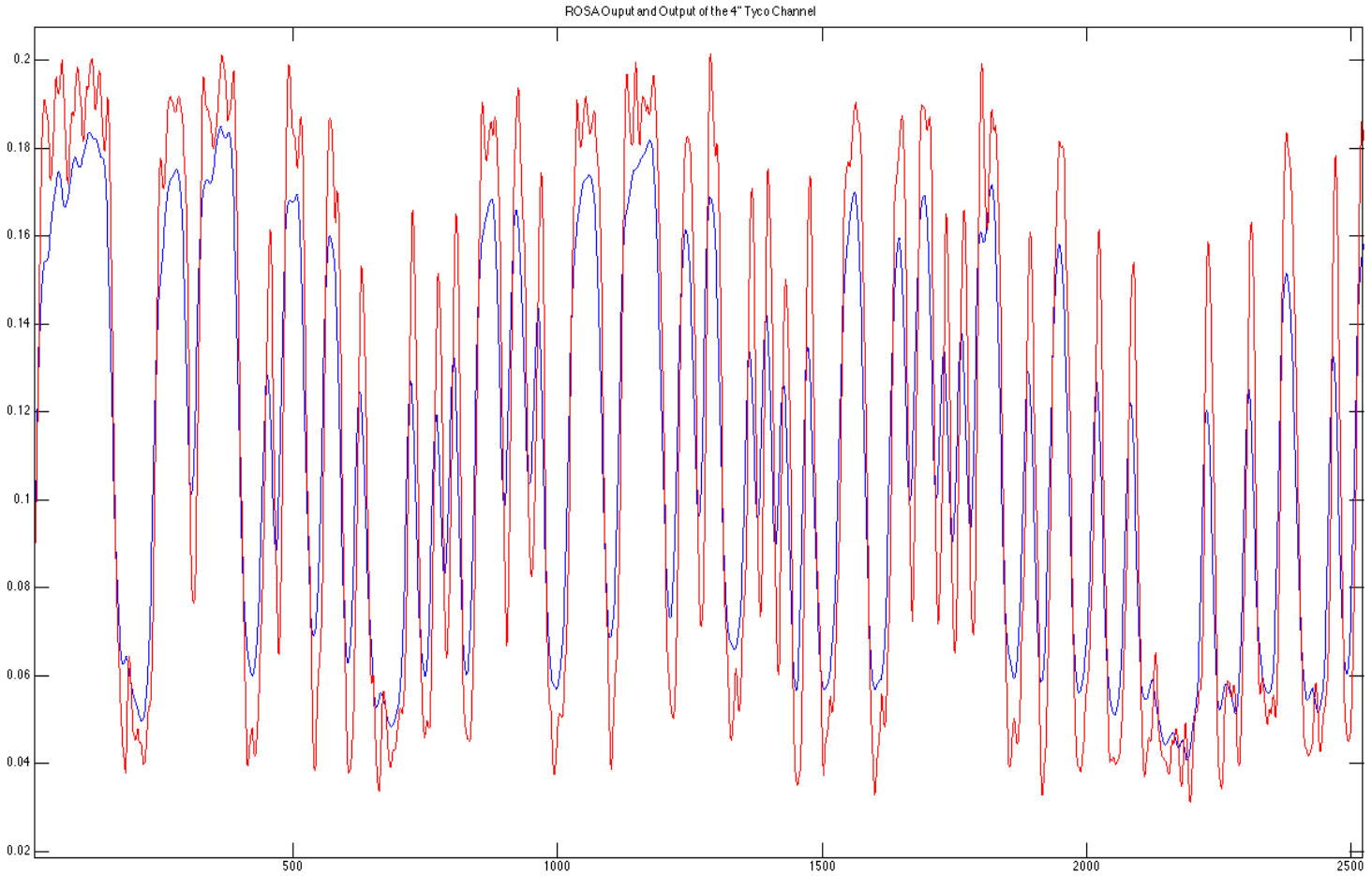
TP5 Eye for the Linear Fiber Model

- After Tyco 4” channel with 1m and 100 m of OM3 fiber



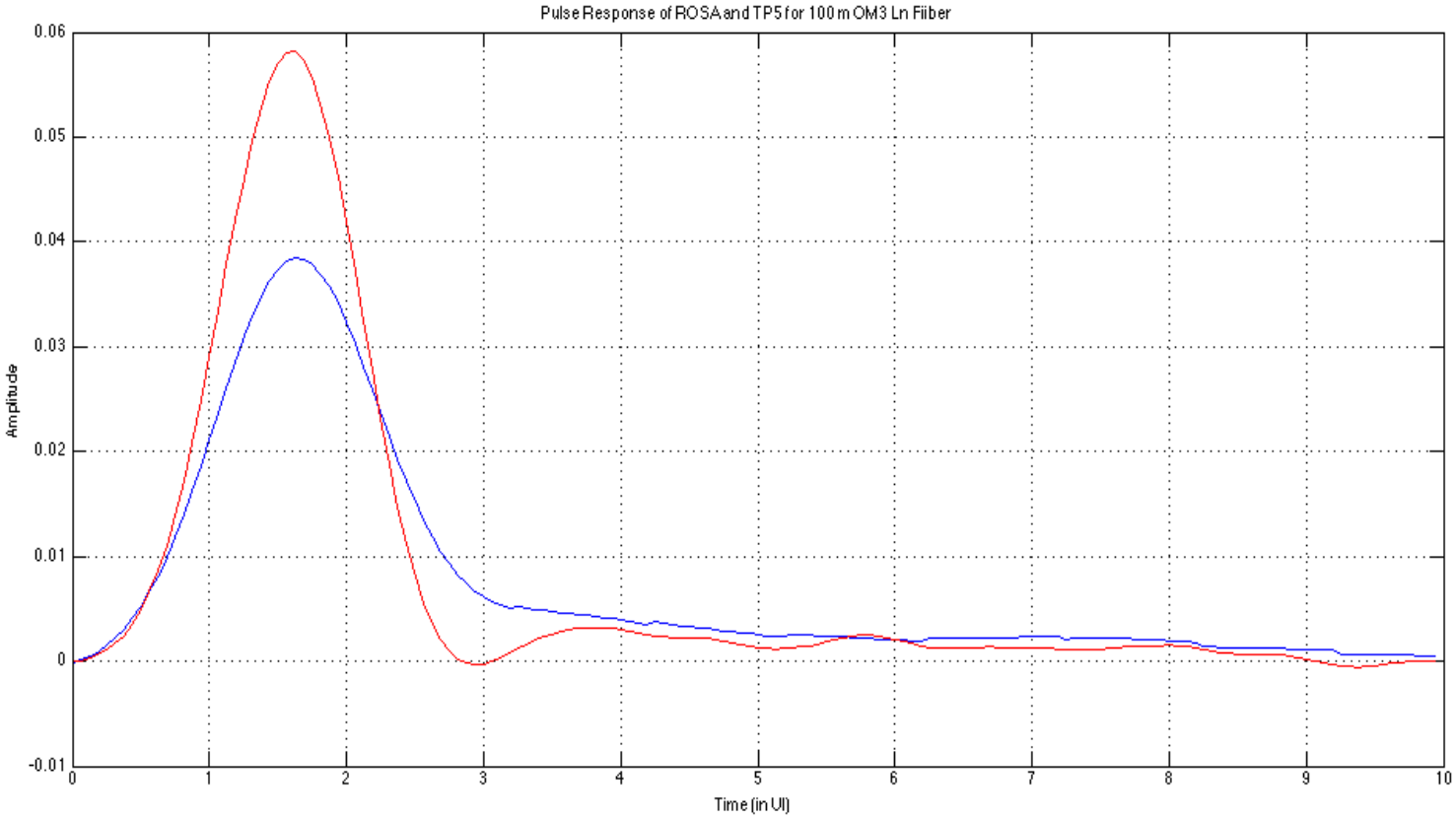


ROSA and TP5 Waveform after 100 m of OM3 fiber Linear Fiber Model



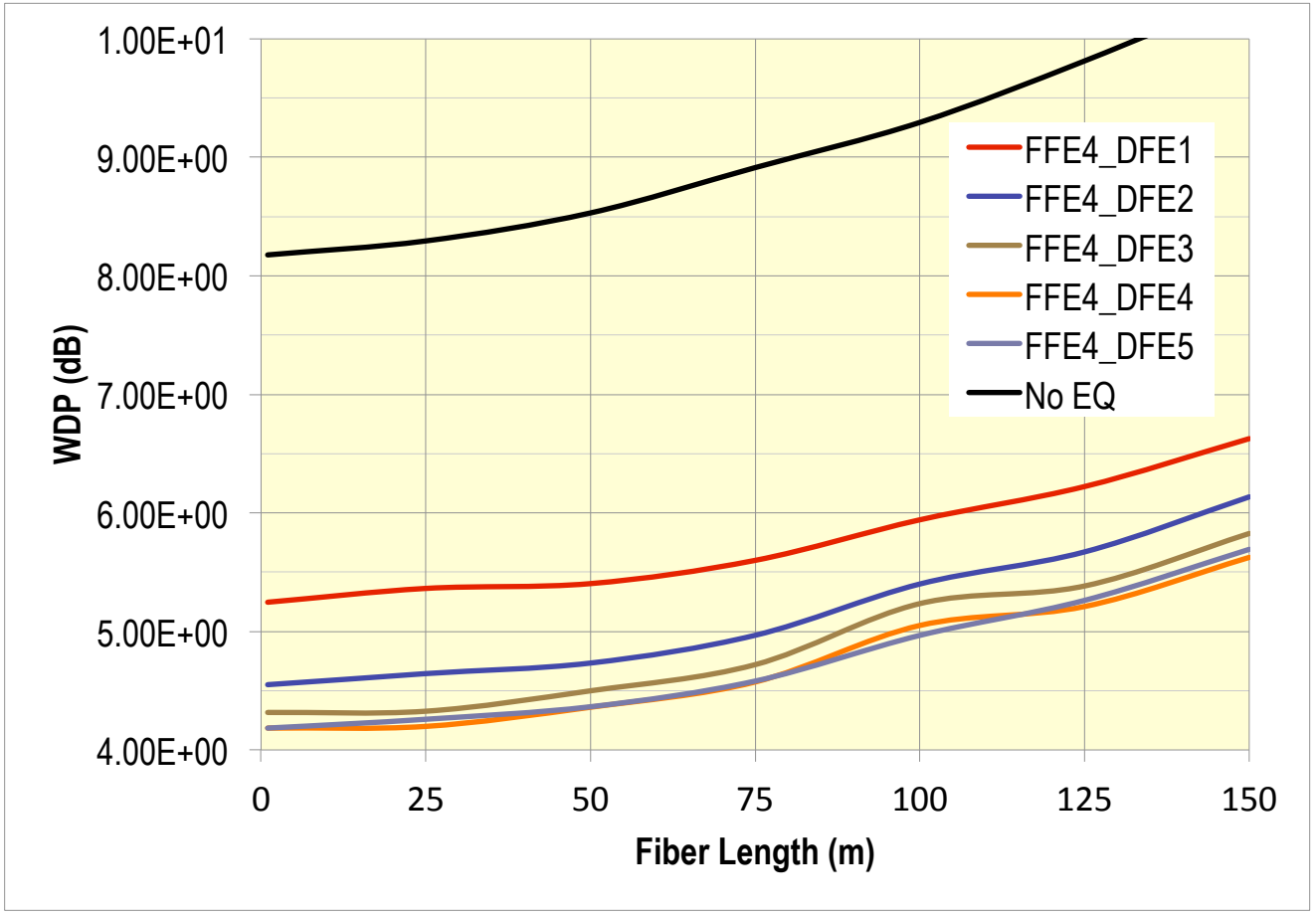
ROSA and TP5 Pulse Response for 100 m Om3 Linear Fiber Model

- Red ROSA output and blue is the TP5



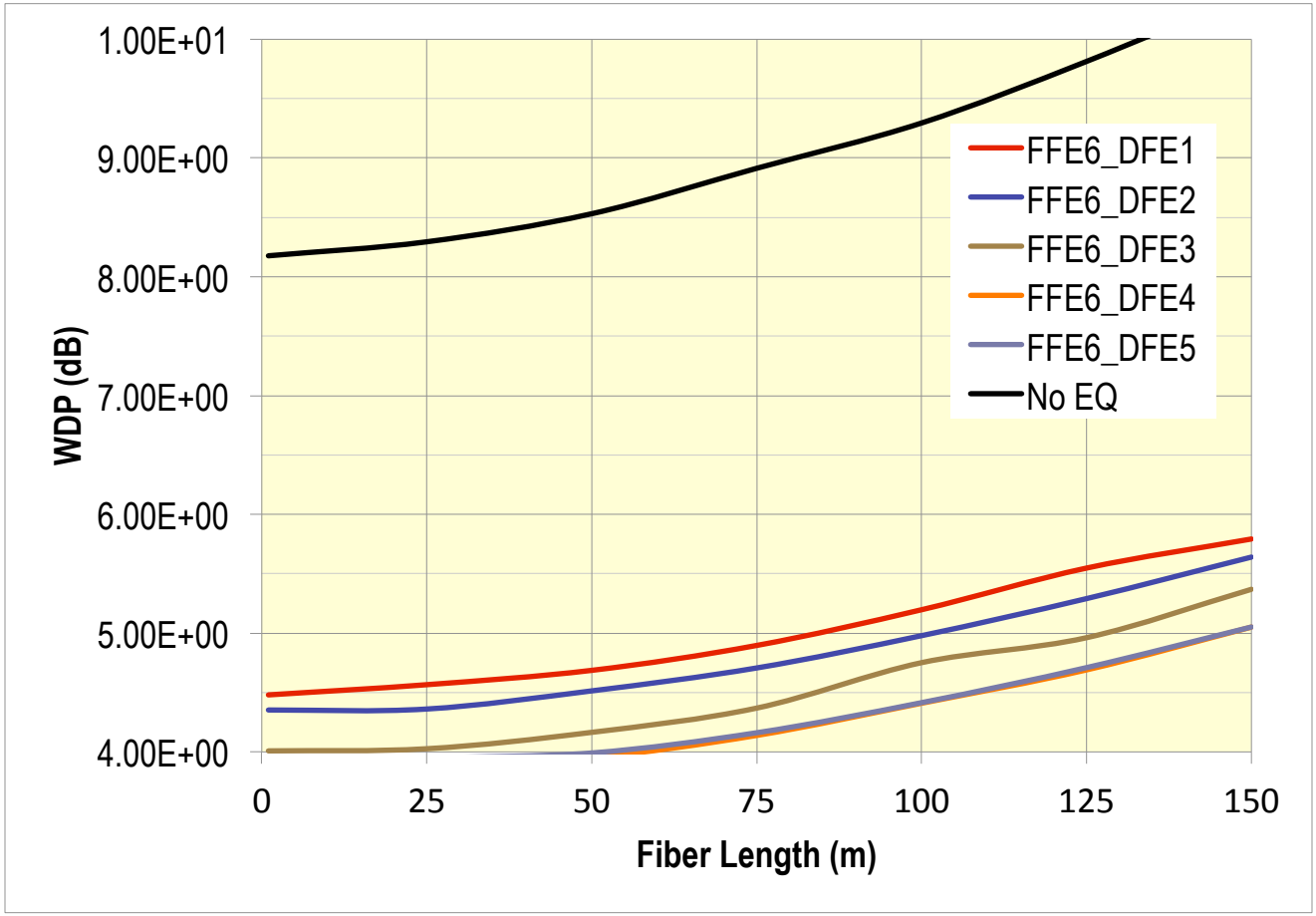
TP5 WDP Penalty for Ln Fiber

- For 4 tap FFE with varying DFE



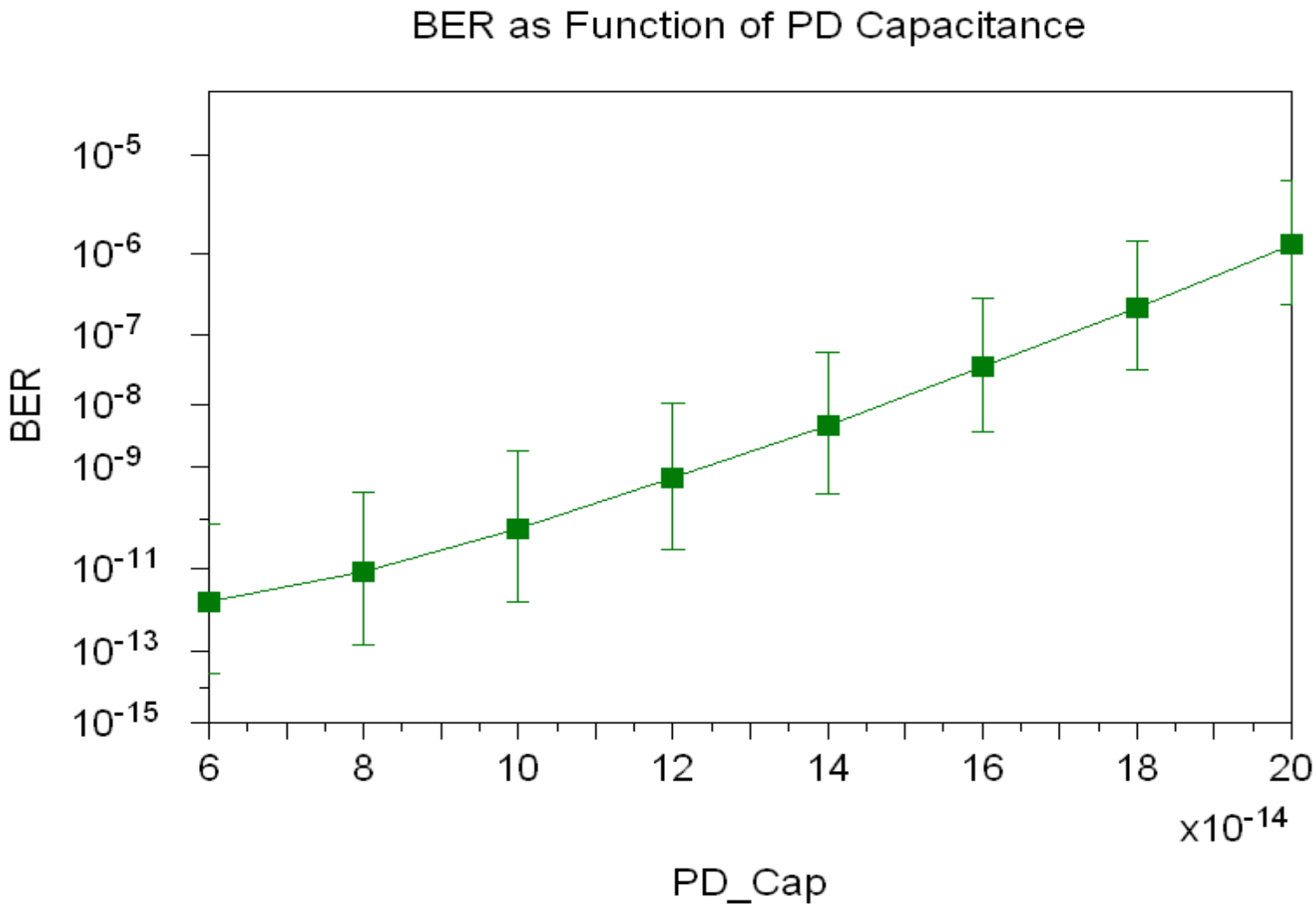
TP5 WDP Penalty for Ln Fiber

- For 6 tap FFE with varying DFE



Receiver BER as Function of PD Capacitance

- All reported results previously were done with 120 ff cap



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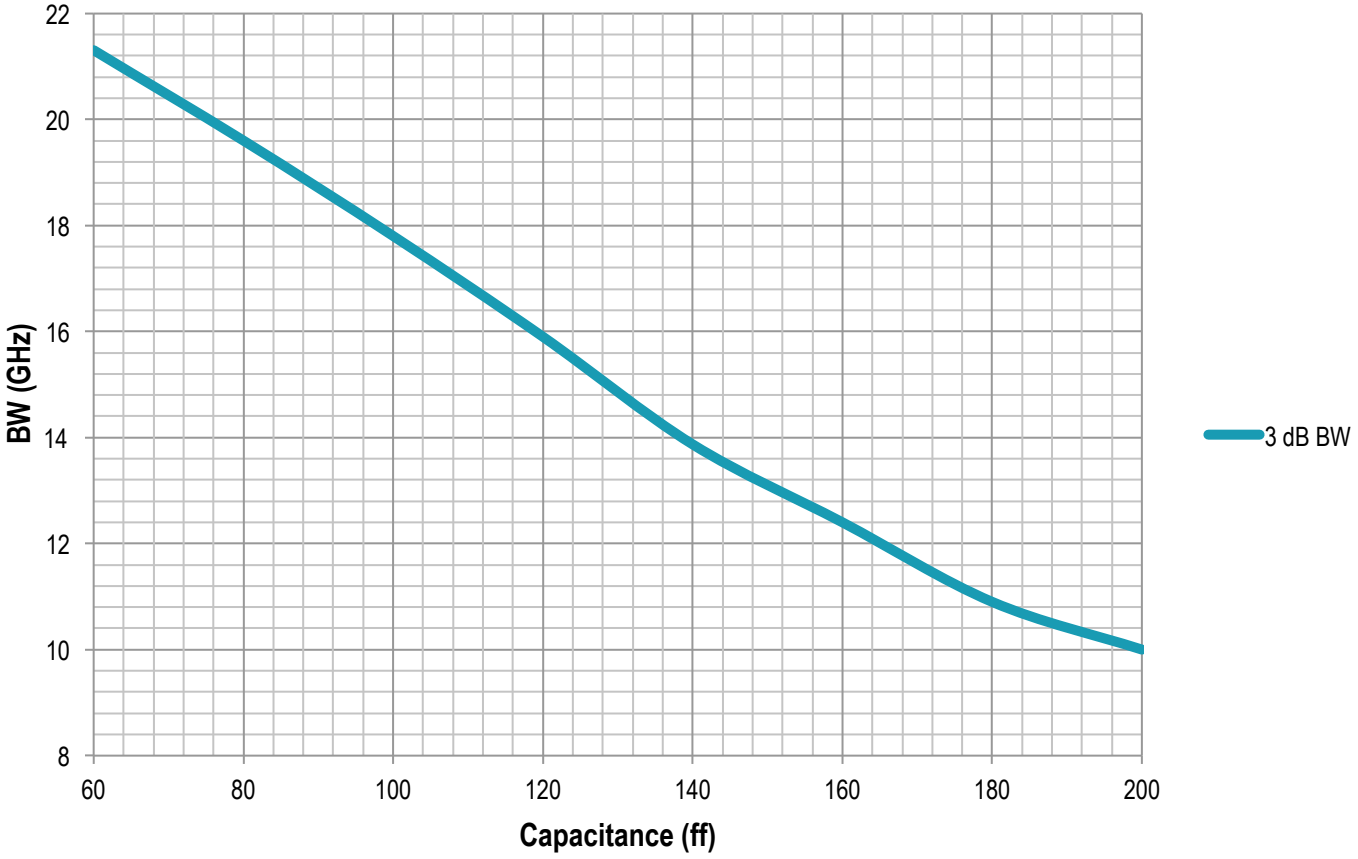
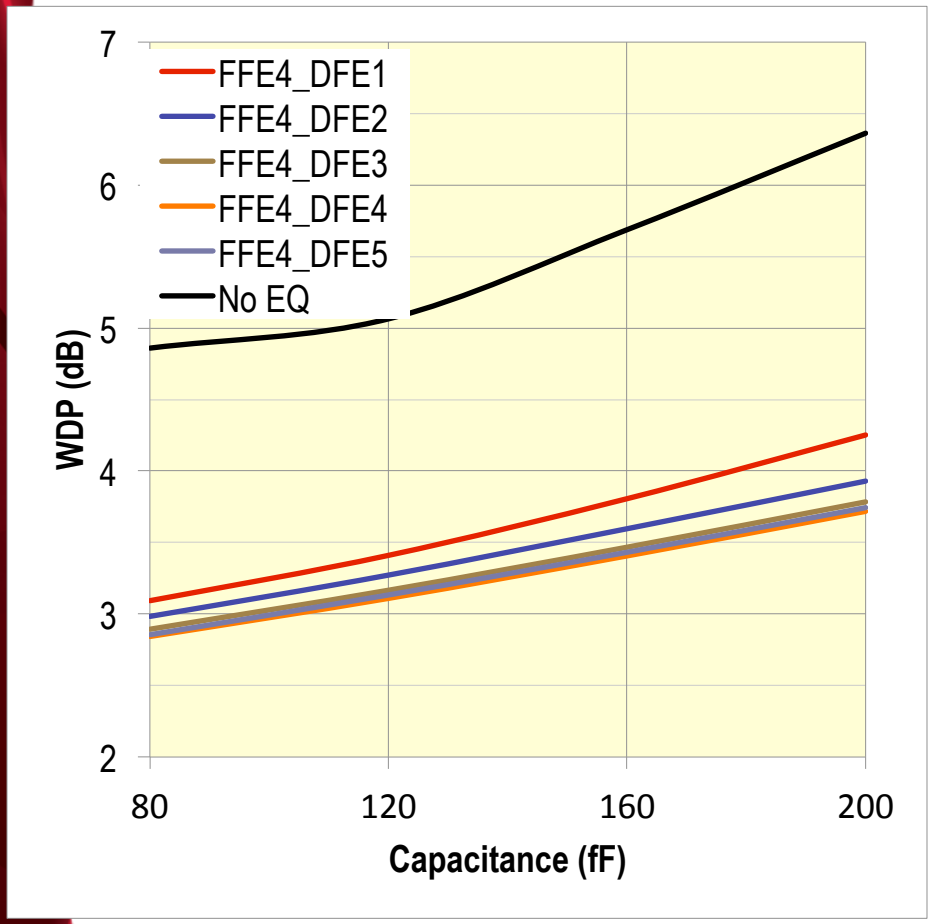
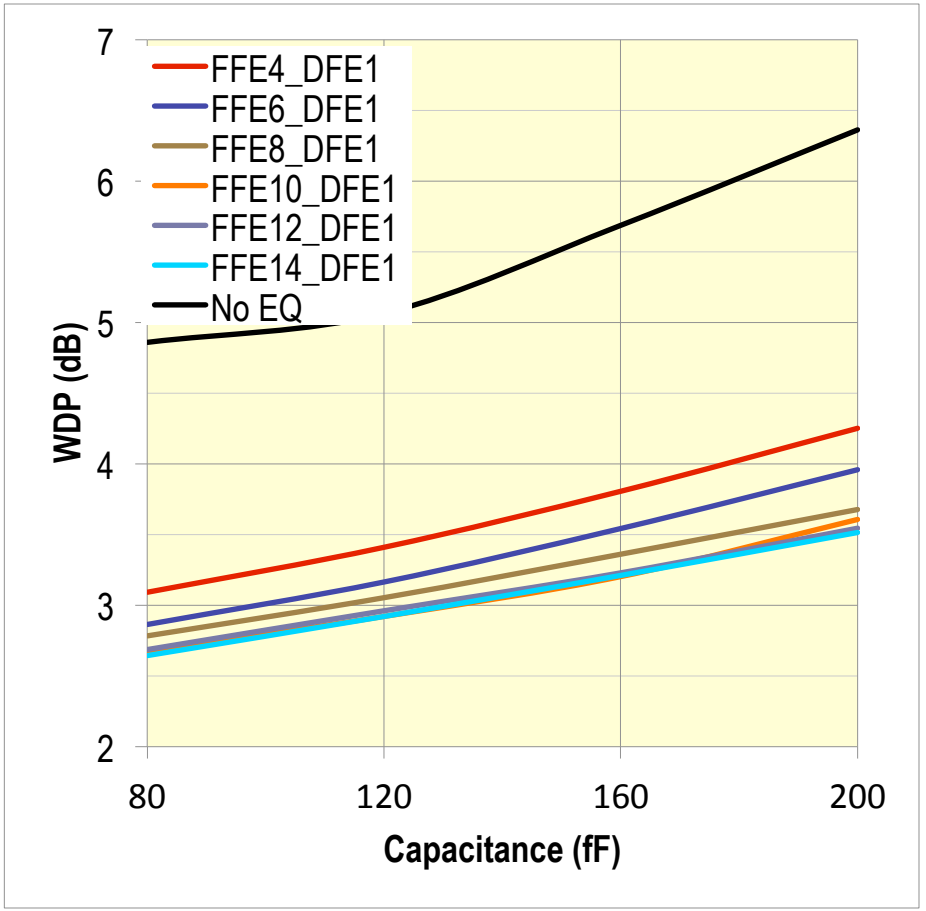


WDP Penalty as Function of RX BW

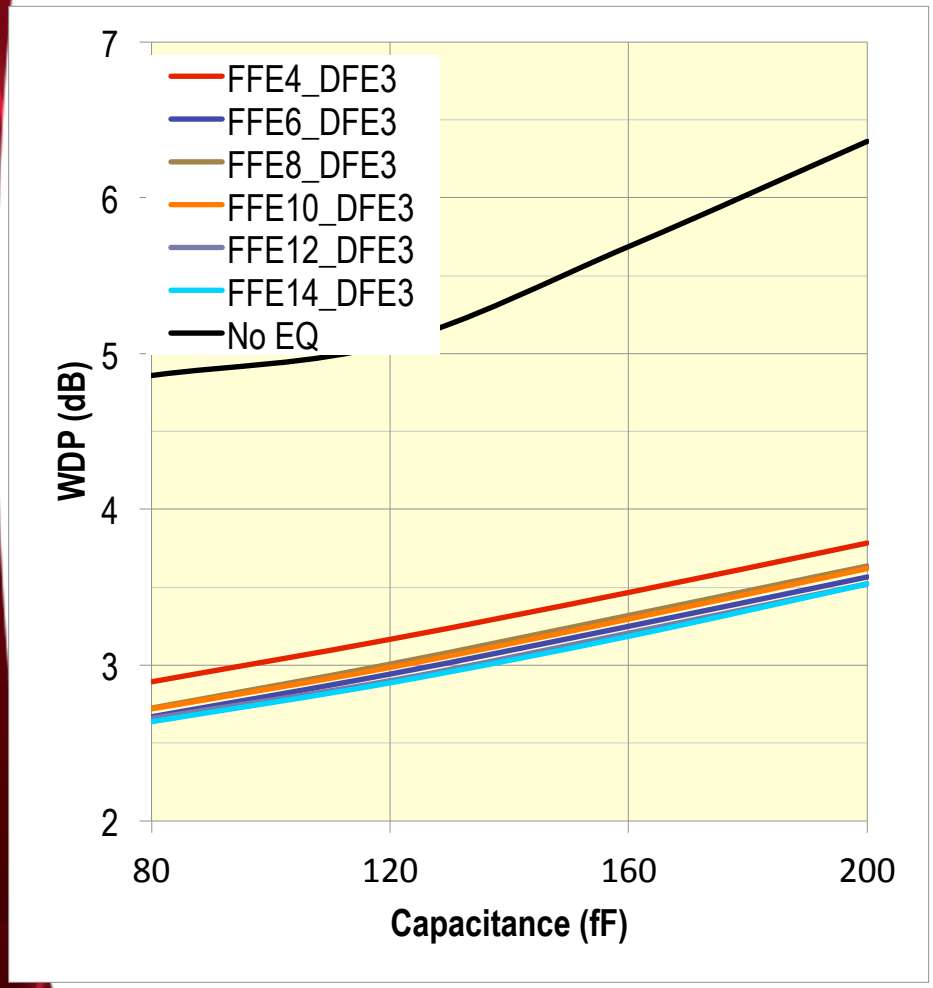
- Fiber 100 m Ln

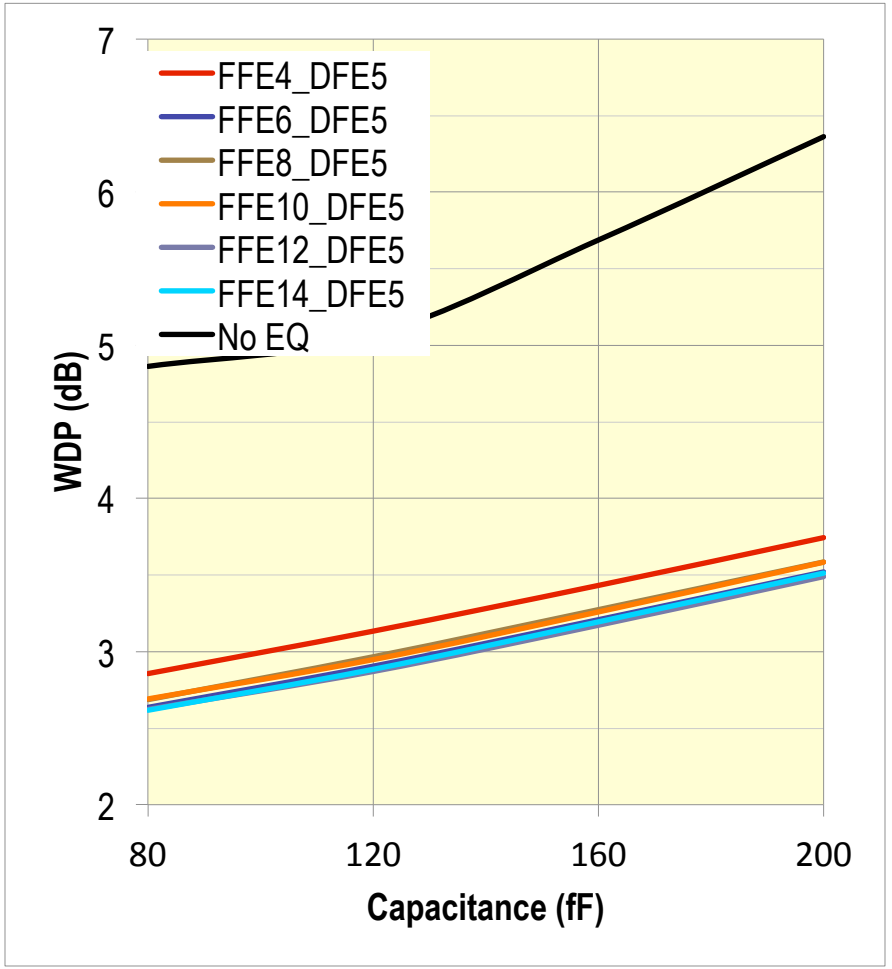




WDP Penalty as Function of RX BW

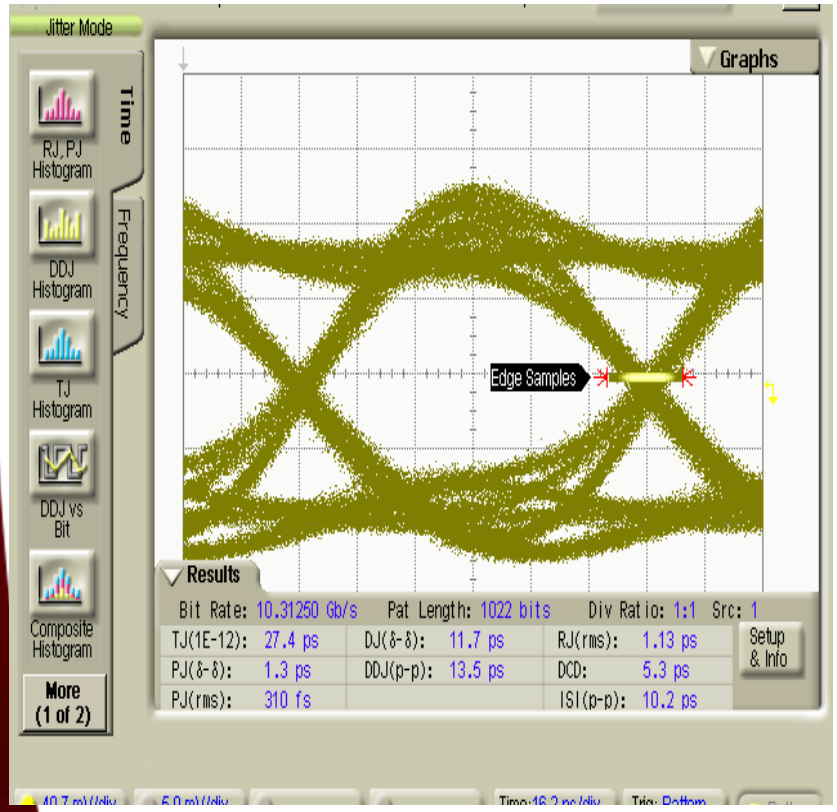
- Fiber 100 m Ln

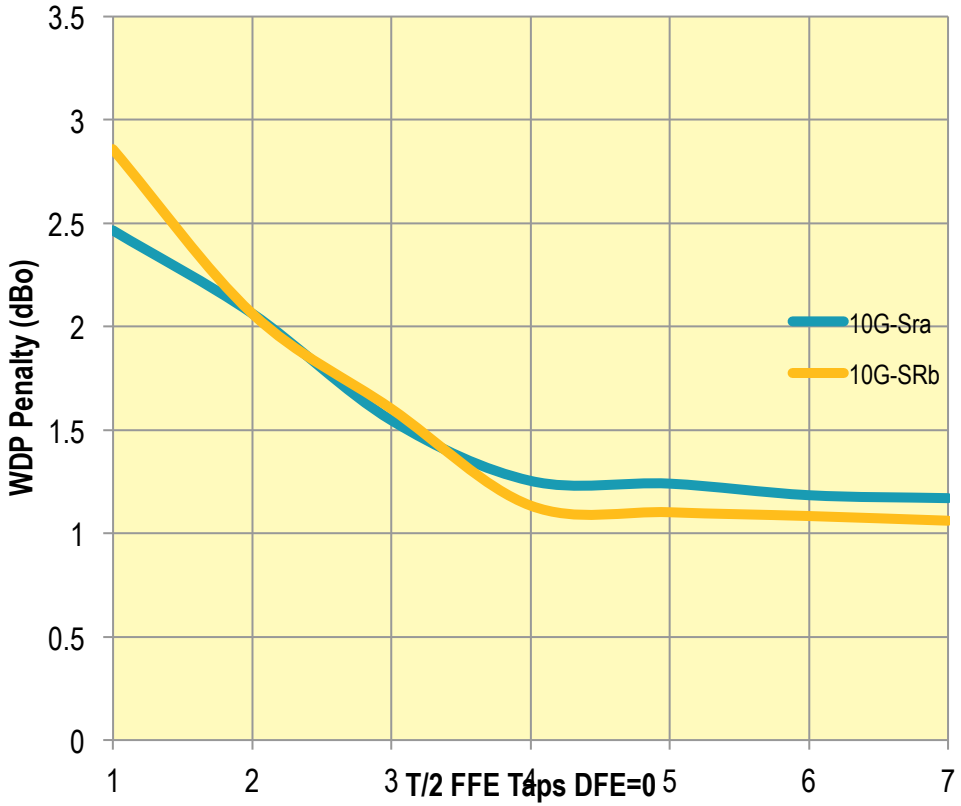




Eye Diagram and Penalty for Typical 10G-SR SFP+

- Penalty for typical 10G-SR VCSEL measured with 7.5GHz receiver





Overview of Penalties

- **Green mean feasible assuming maximum WDP penalty of 5 dBo**
- **Red mean non feasible with EQ alone but could become feasible with FEC**
  - MPN penalty not included in these results

Impairment Source	No EQ	FFE=4, DFE=0	FFE=6, DFE=0	FFE=6, DFE=3
10G-SR link B2B	2.6 dBo	1.2 dBo	1.1 dBo	1.05 dBo
25G link B2B BW=0.62*B	4.1 dBo	2.9 dBo	2.5 dBo	2.4 dBo
25G 100m OM3 BW=0.62*B	5.2 dBo	3.8 dBo	3.4 dBo	3.0 dBo
25G 100m OM3 BW=0.5*B	5.9 dBo	4.2 dBo	3.7 dBo	3.3 dBo
25G 100m OM3 BW=0.62*B At TP5	9.3 dBo	6.1 dBo	5.3 dBo	4.7 dBo

Summary

- **Investigated 25.78 GBd VCSEL link based on rate equation with both linear fiber with 2000 MHz.km and spatial fiber model**
  - In case of LRM, fiber manufactures provided 1000's of fiber modal delay but in case of 100G-SR4, fiber is not dominant in either 100 m OM3 or 150 m OM4
  - Since VCSEL dominates the overall penalty with ~4 dBo of optical penalty
  - MPN noise need to be quantified in these longer reach application with equalizer
- **Spatial fiber model producing pre and split fiber response meeting 0.32 ps/m of DMD has lower penalty than linear fiber model with 2000 MHz.Km**
- **Assuming the target WDP penalty is a modest 3.5-4 dBo then various equalizer options exist to support at least 100 m of OM3 or 150 m of OM4 fibers**
- **Investigation of the unretimed cPPI-4 based on 4" Tyco channel with N4000-13SI has penalty <5 dBo with modest 6-T/2FFE+3 DFE EQ**
- **Benefit of equalized link**
  - Solves VCSEL slow fall time and chromatic dispersion as result of spectral width
  - Relax photo detector capacitance
  - Could support full 100 m on OM3 or 150 om on OM4
  - Link could operate without FEC addressing latency sensitive applications
  - Unretimed implementation will have lowest PD without compromising on the fiber reach!

Summary

- Benefit of equalized link
- Solves VCSEL slow fall time
- Solves VCSEL spectral width
- Solves photo detector capacitance
- Could support full 100 m on OM3 or 150 om on OM4
- Link could operate without FEC addressing latency sensitive applications
- The unretimed link will have the lowest power
- As SFP+ has shown the unretiemd link at 25G will also offer the lowest cost, power, and size