

# Simulations of 100G-SR4 Link

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IEEE 802.3 100GNGOPTX Study Group

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# 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 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 “Spatial 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.**

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

# VCSEL and Link Model

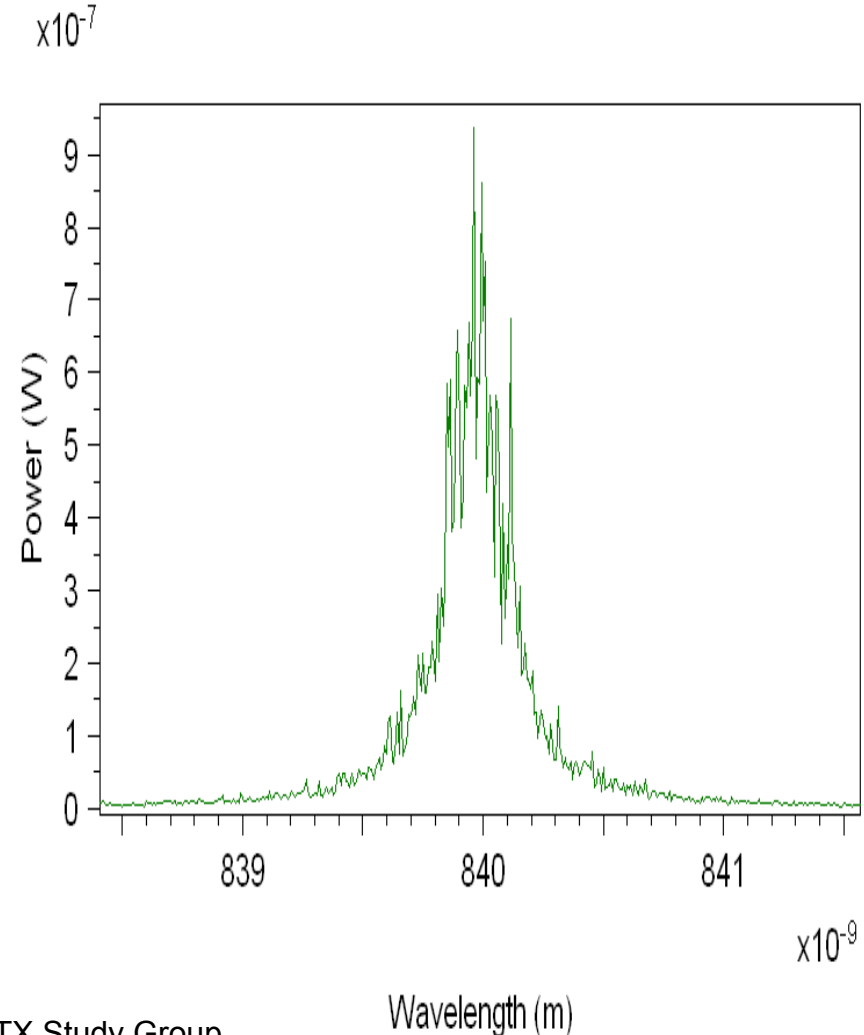
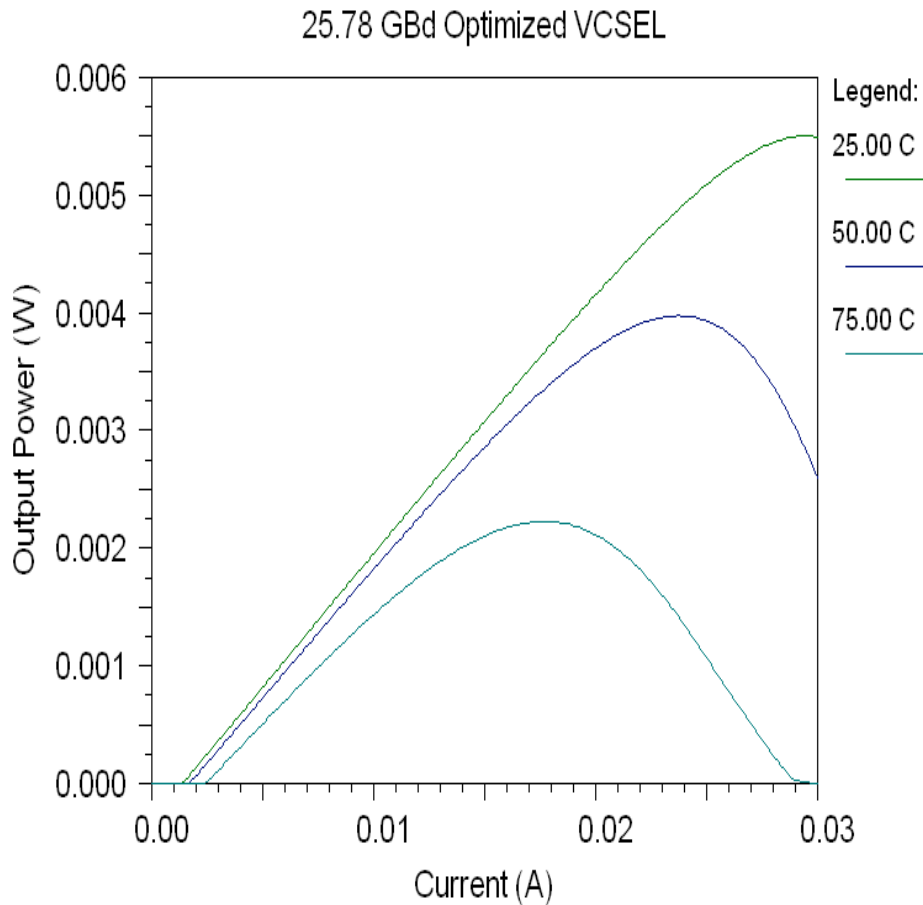
- **Simulation environment RSOFT**
- **Transmitter parameters**
  - VCSEL model based on spatial rate equation optimized for 25.78 GBd Center wave length=840 nm
  - Spectral width = 0.6 nm
  - VCSEL RIN = -129 dB/Hz
  - Mode size 7.5 um and offset launched by 7.5 um
  - 4 ps p-p PJ was added to the electrical driver
  - ER ~ 6 dB
  - Operating Temp=25 C
  - Direct measurement of pulse  $Tr_{10-90\%}=20$  ps,  $Tf_{10-90\%}=44$  ps,  $Tr_{20-80\%}=14$  ps,  $Tf_{20-80\%}=22$  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 k $\Omega$
- **Fiber /link Parameters**
  - $S_0=0.10275$  ps/nm<sup>2</sup>.km,  $\lambda_0=1316$  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

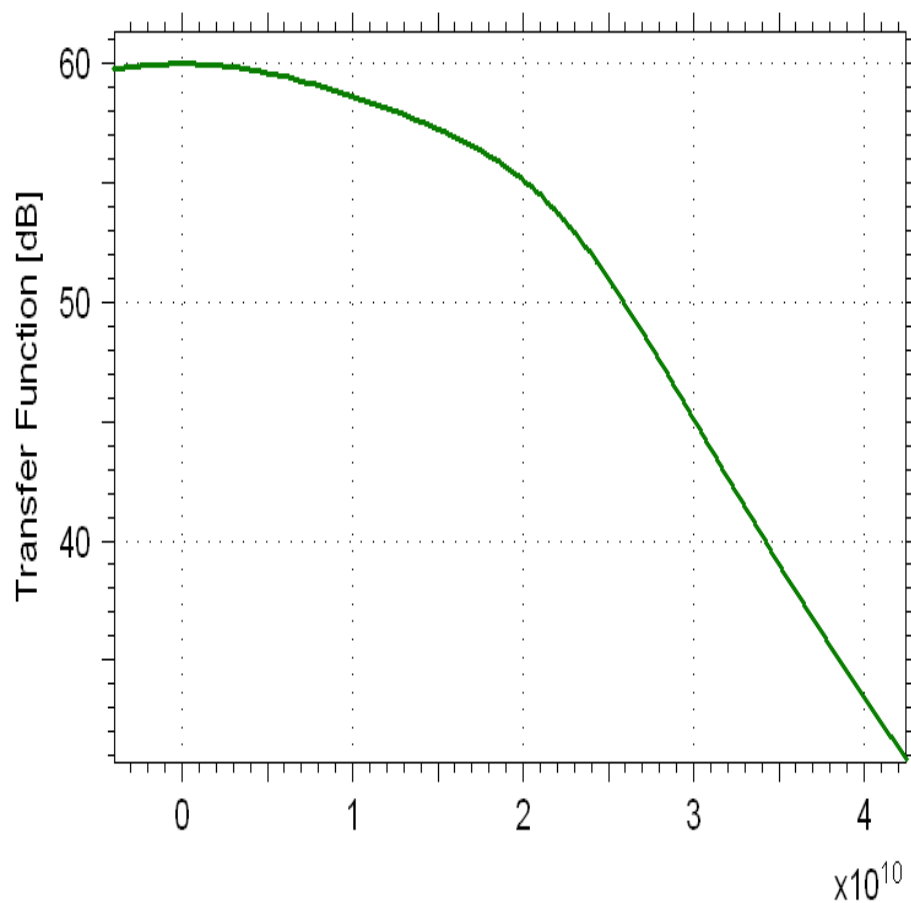
25G VCSEL Spectrum



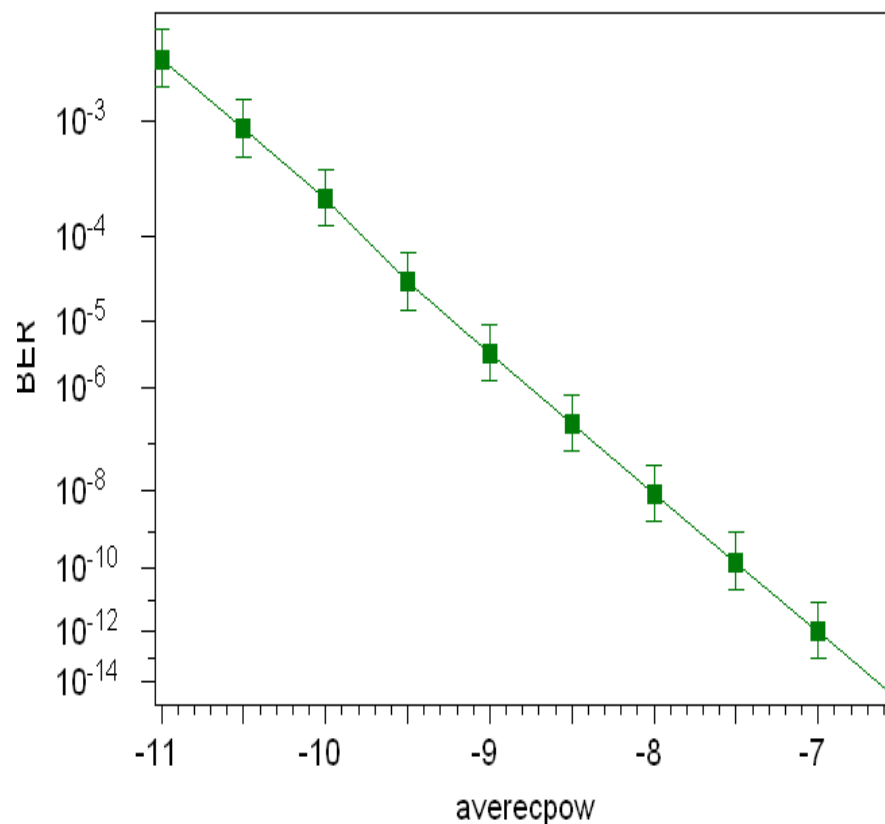
# PIN/TIA

- TIA has  $TZ=1\text{ k}\Omega$ , with BW of 15.75 GHz and sensitivity of -7 dBm with MZ source with ER=6 dB

PD/TIA Response

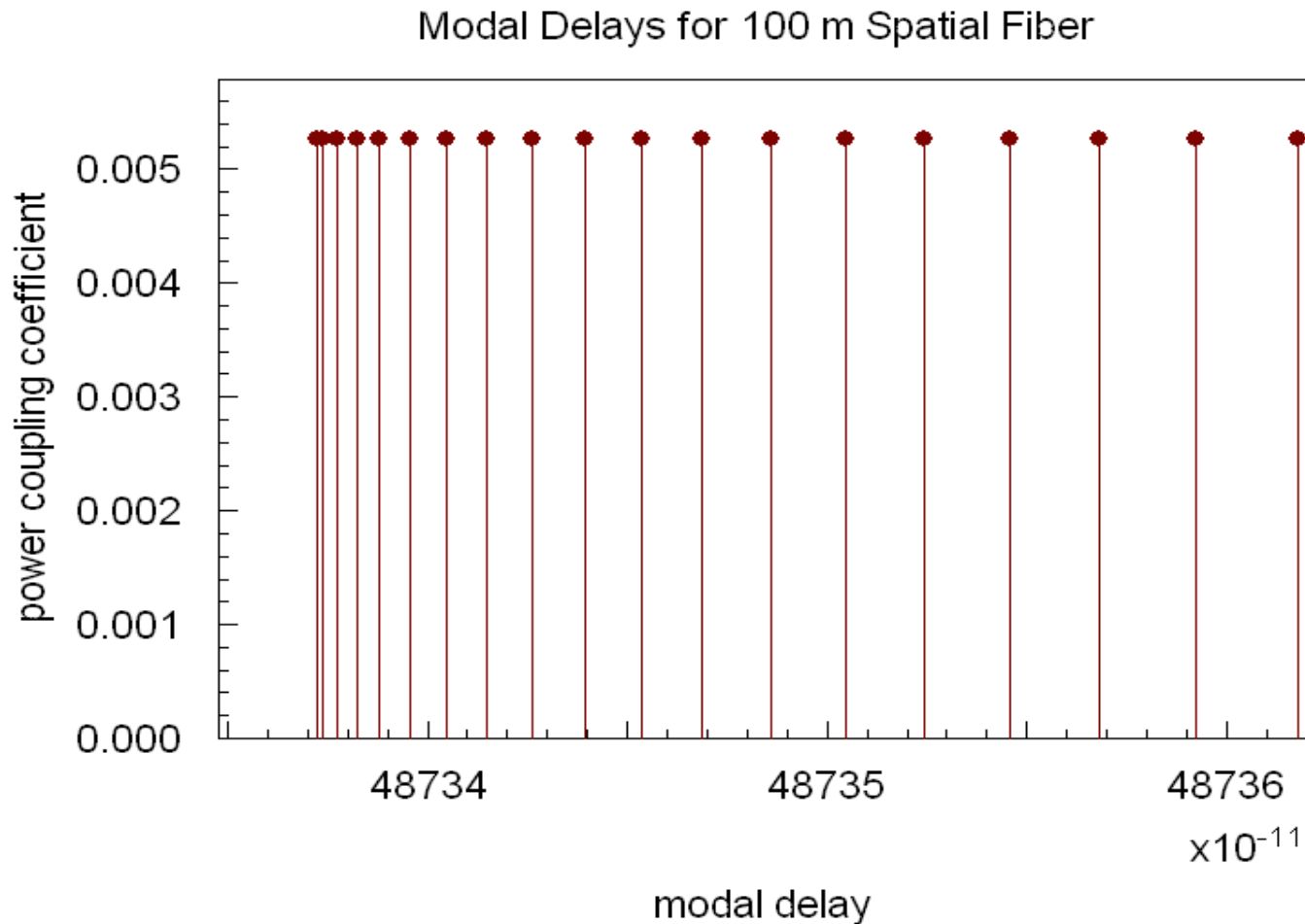


Receiver Sensitivity with MZ Source ER=6 dB



# Spatial Fiber Mode Delays

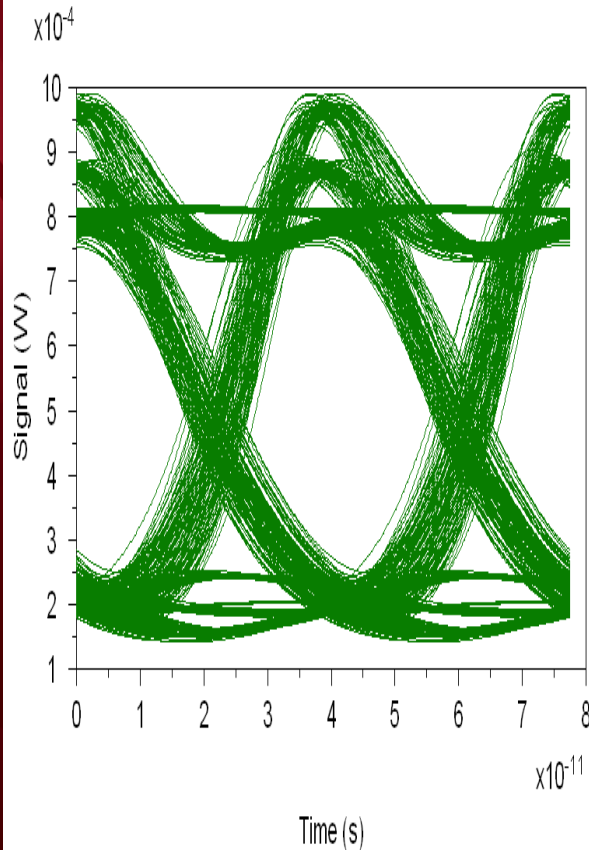
- This fiber has pre-cursor response other fiber need to be constructed for split and post response



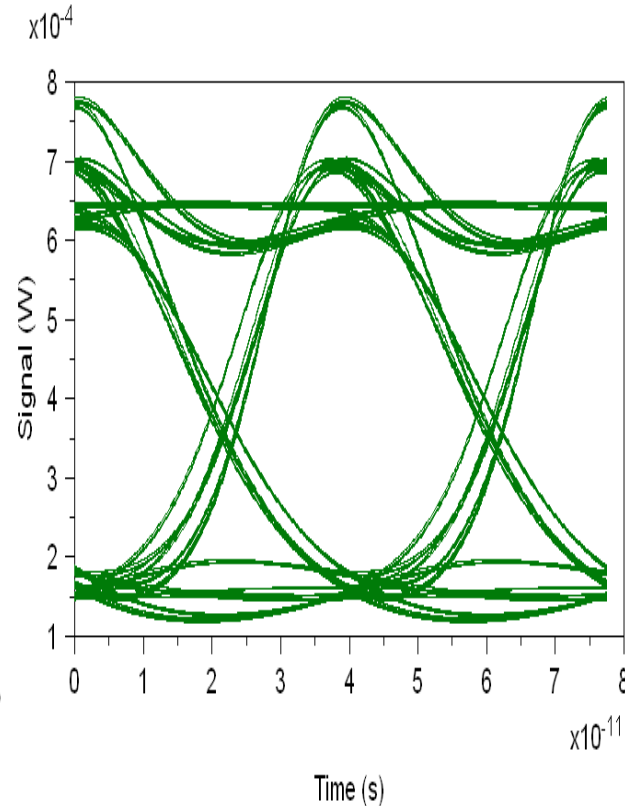
# VCSEL Optical Eyes and Back to Back Eye

- Model based on RSOF 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

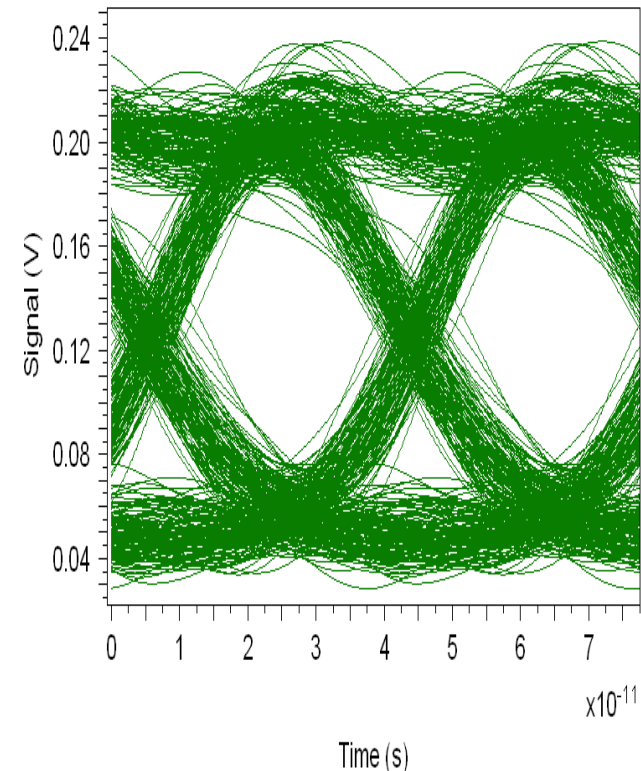
25G VCSEL Optical Eye



VCSEL Optical Eye with PJ=0



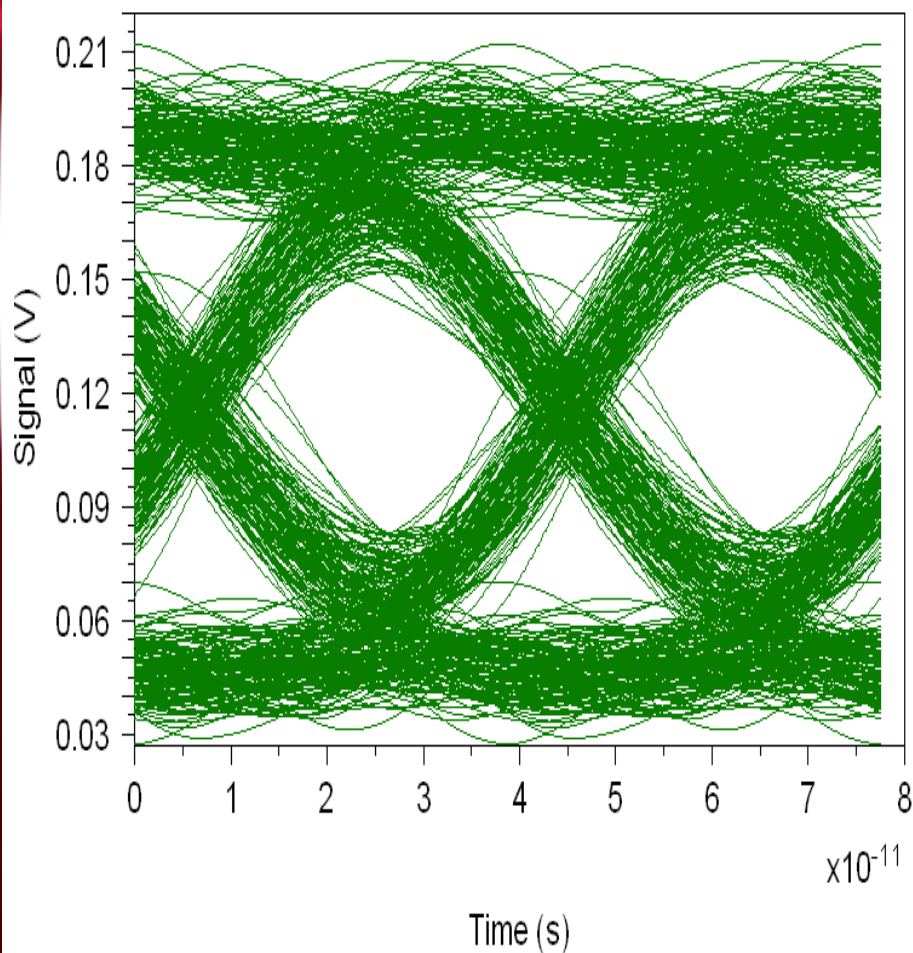
Near End 1 m Optical Eye



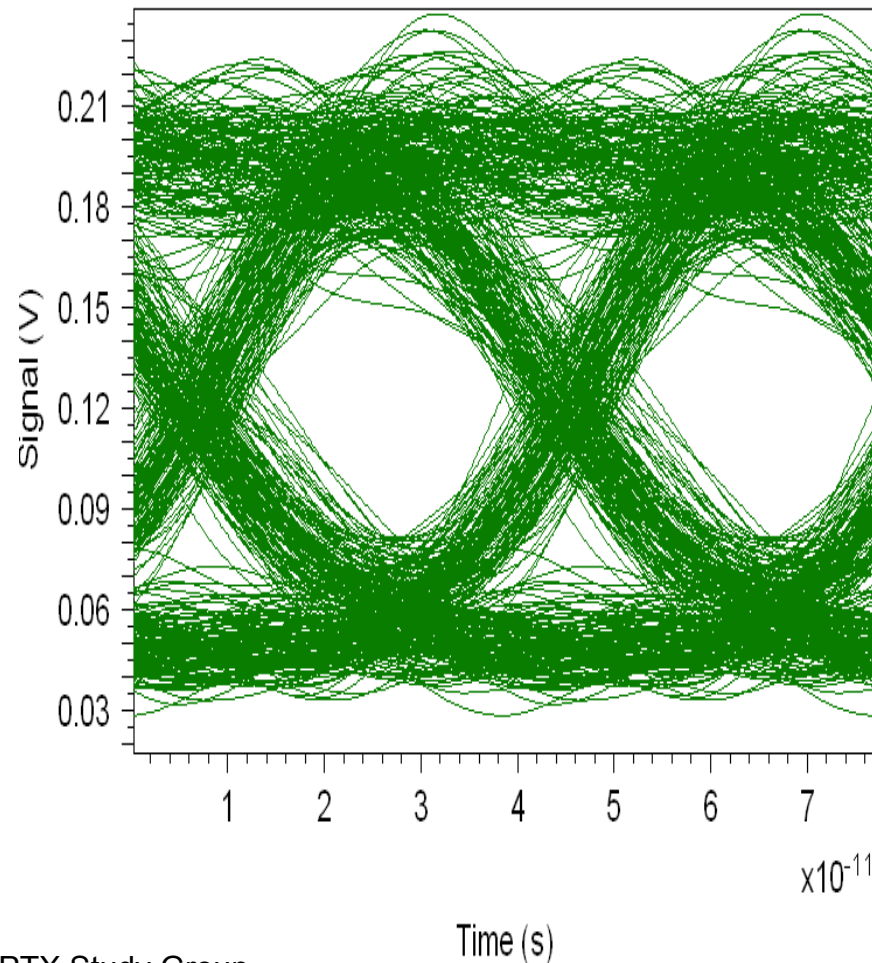
# Far End Eye Diagram for 100 m OM3 Fiber

- For linear and parabolic model at -3 dBm

OM3 Eye 100 m with Linear Fiber Model



100m OM3 Spatial Fiber Model

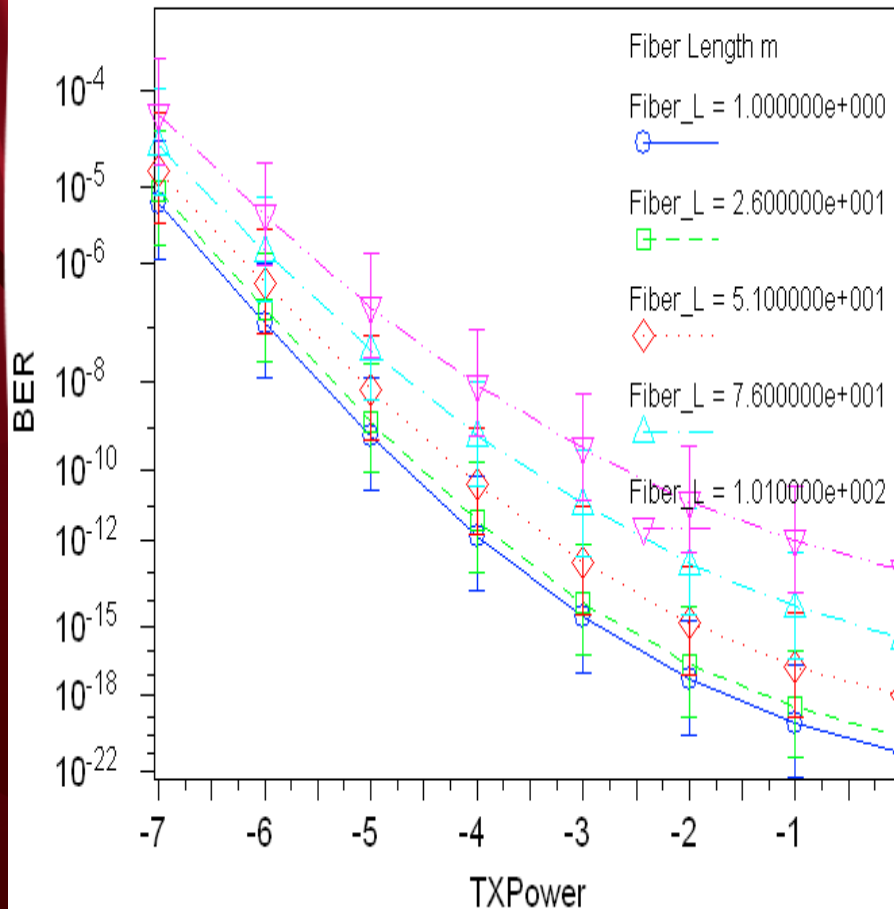




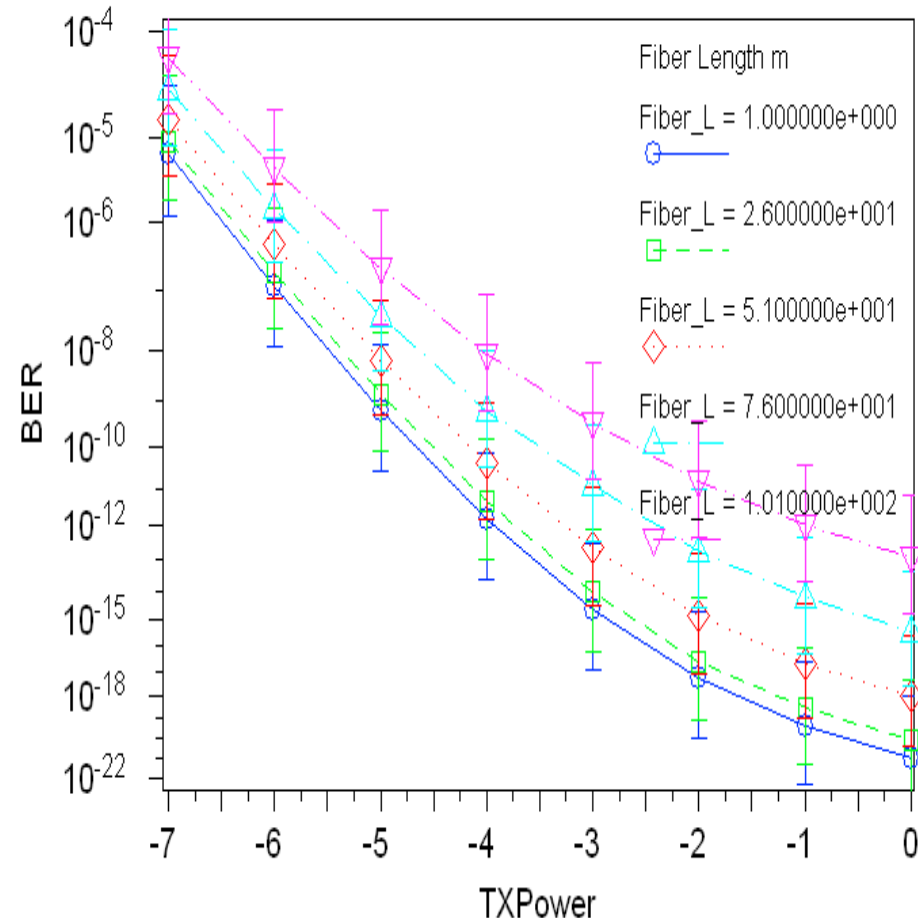
# BER Plot for Linear and Parabolic OM3 Fiber Model

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

Linear OM3 Fiber as Function of Length and TX Power



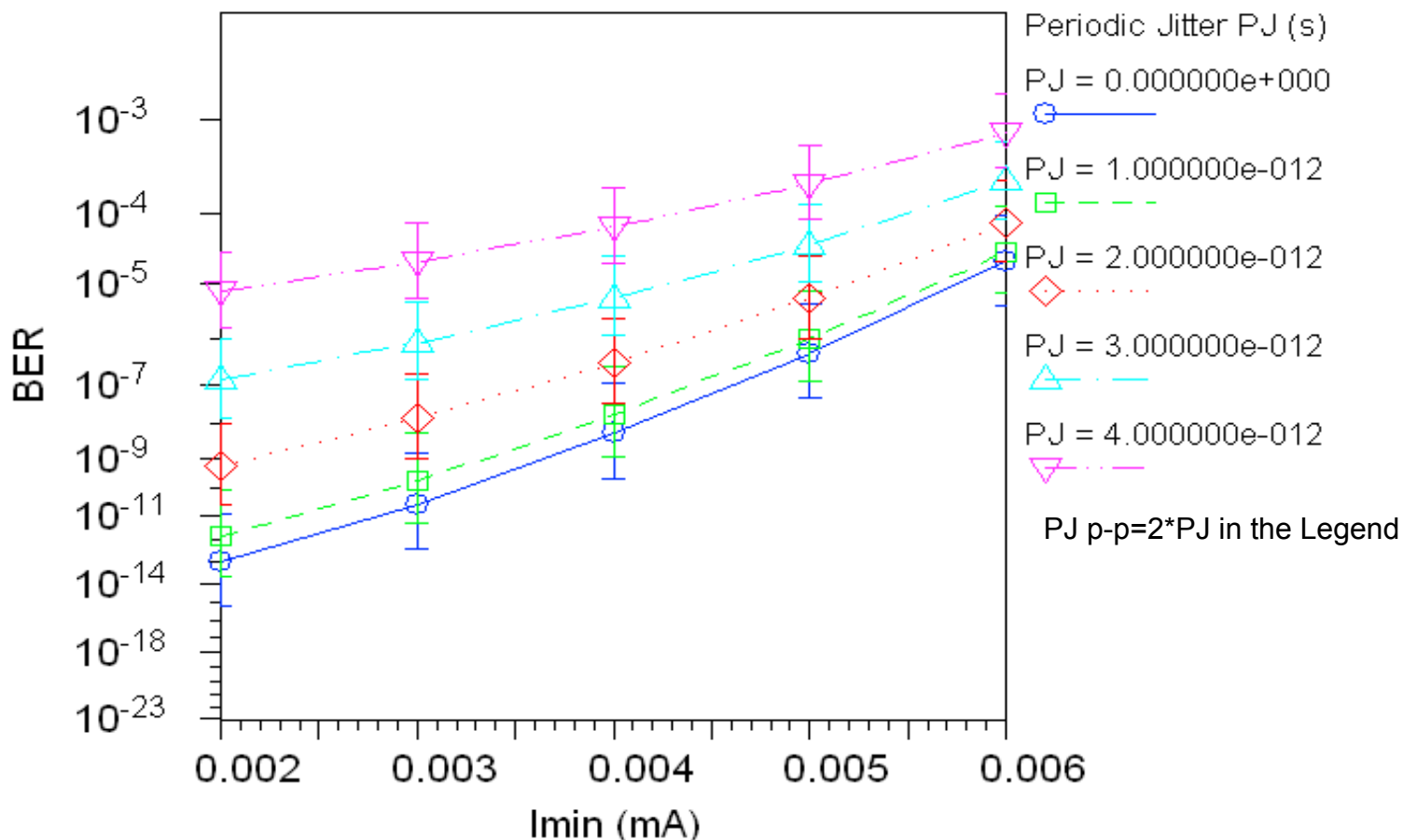
Spatial OM3 Fiber BER as Function of Length and TX Power



# 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

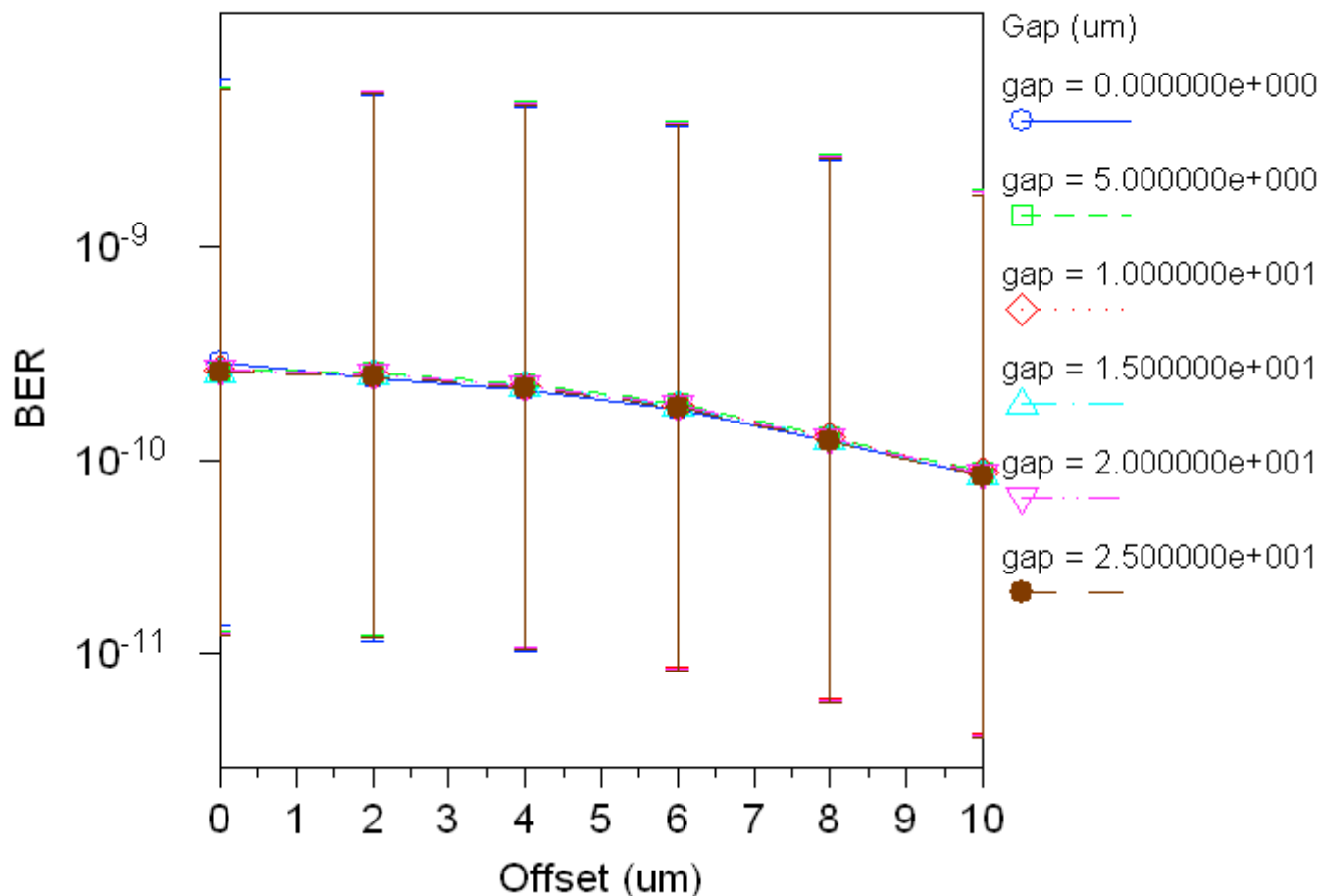
BER as function of ER and PJ



# Sensitivity as Function of Launch Offset and Gap at -3 dBm

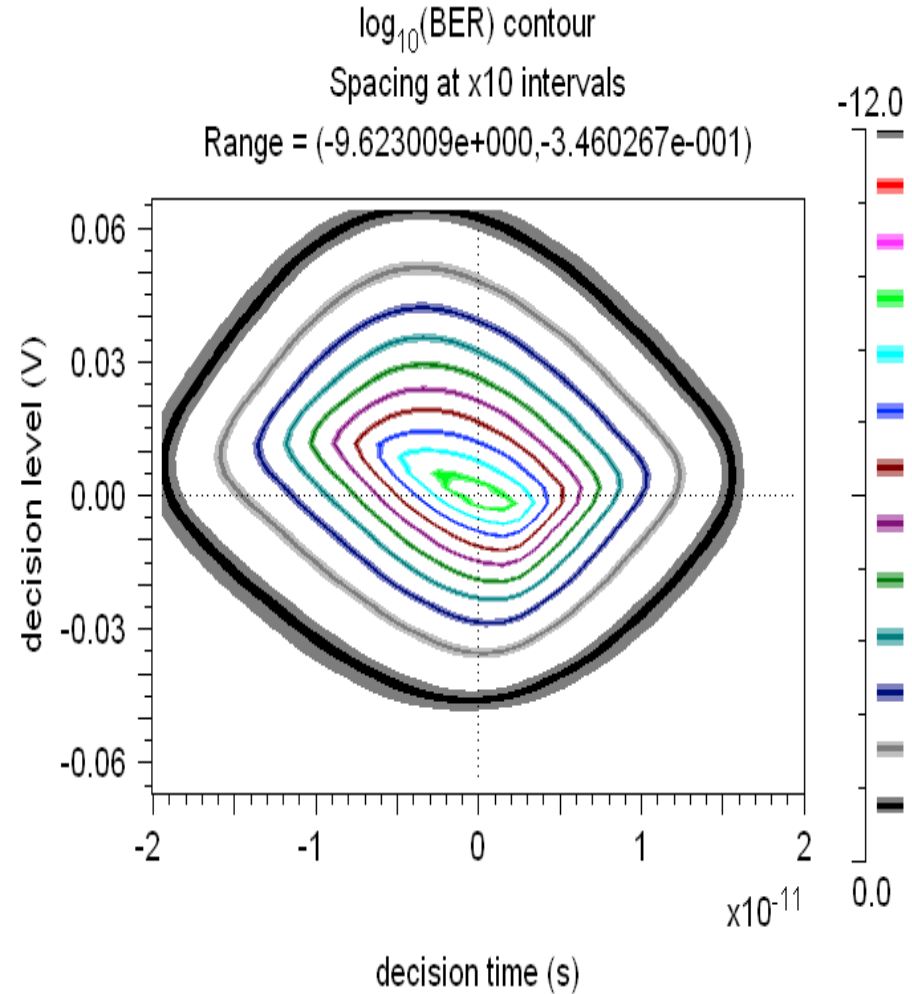
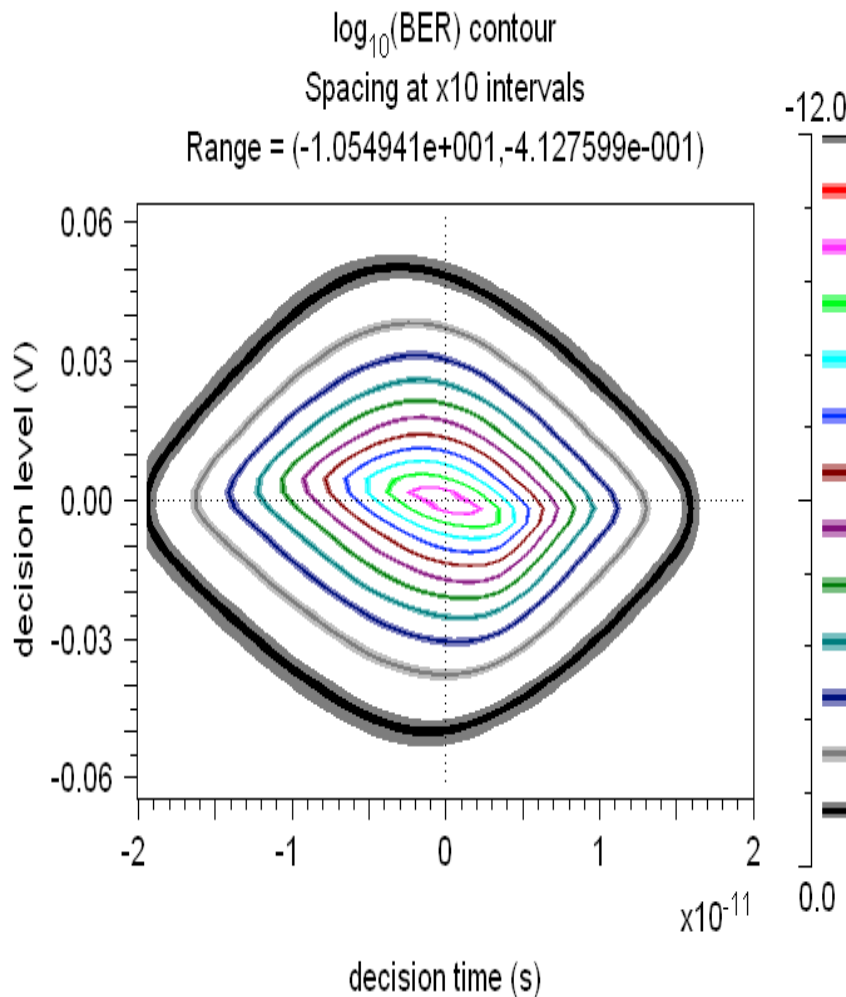
- The spatial fiber profile currently has no structural DMD as alpha was adjusted from ideal fiber to 2.09

BER as Function Connector Offset and Gap



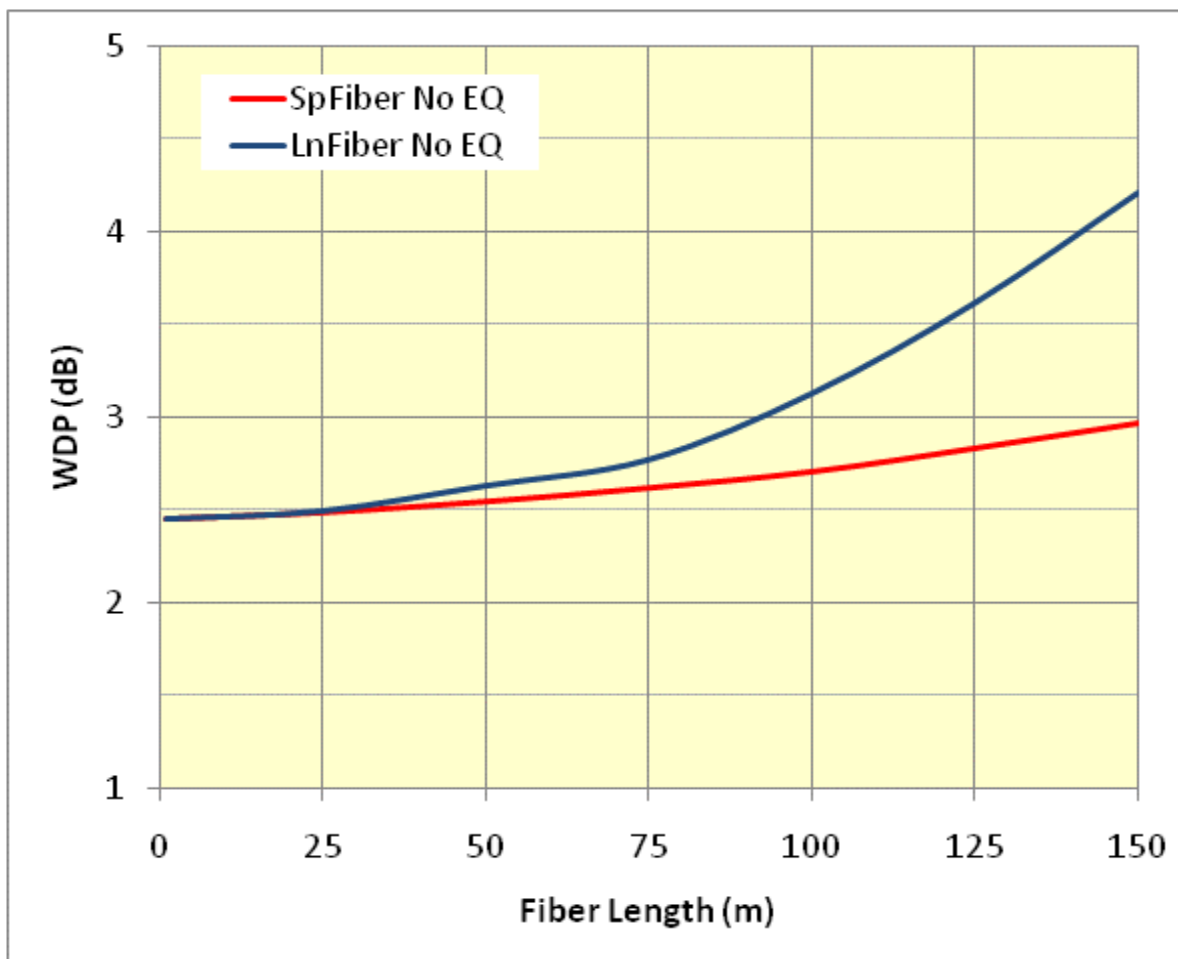
# BER Contour for 100 m Fiber Link

- At -3 dBm for linear (left) and spatial (right) neither meet BER 1e-12 at 100 m
  - A 4 dB FEC could turn 1E-6 BER to ~1E-12 and EQ will further improve link margin



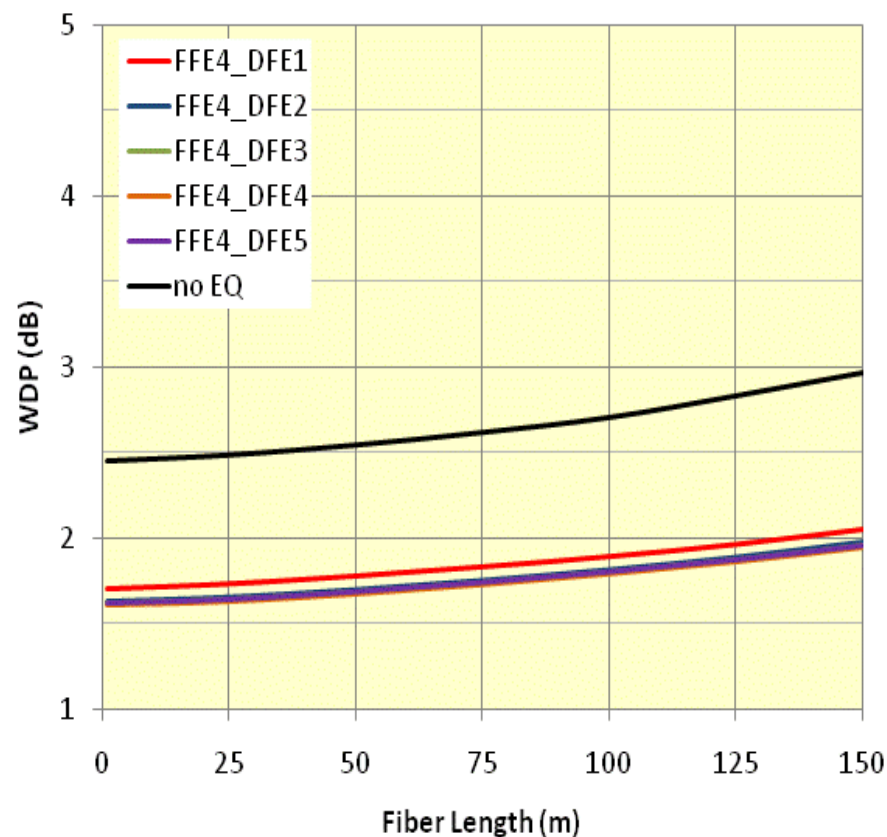
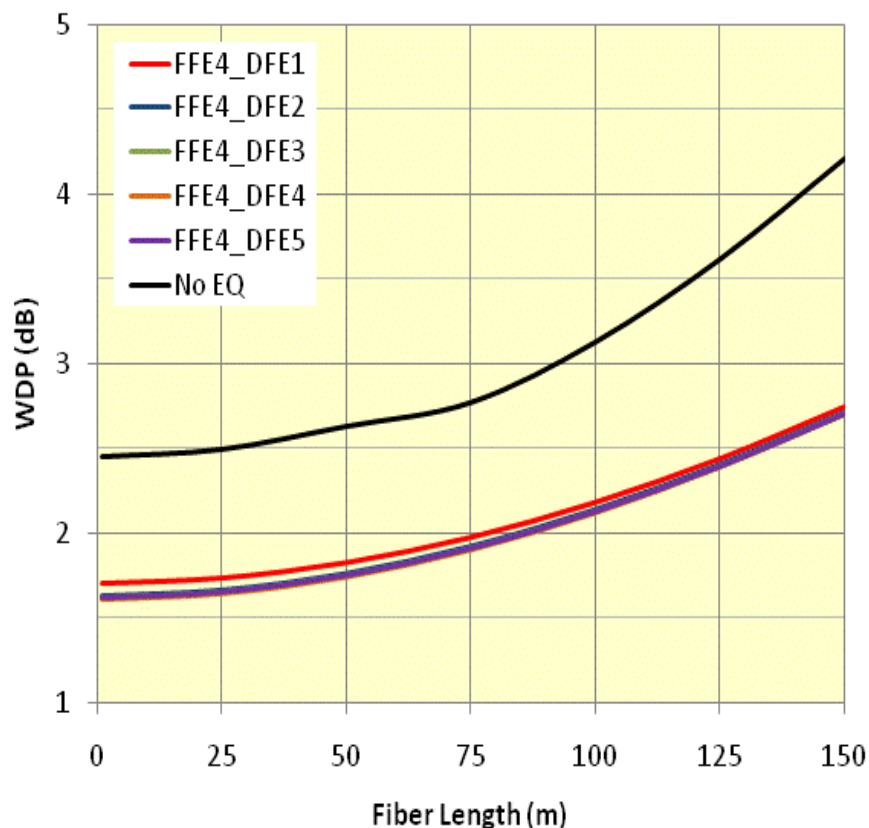
# Link Penalty Without Equalizer

- Penalty calculated with on SFF-8431 WDP code
  - Paloc=5.5 dBo was used instead of LRM 6.5 dBo



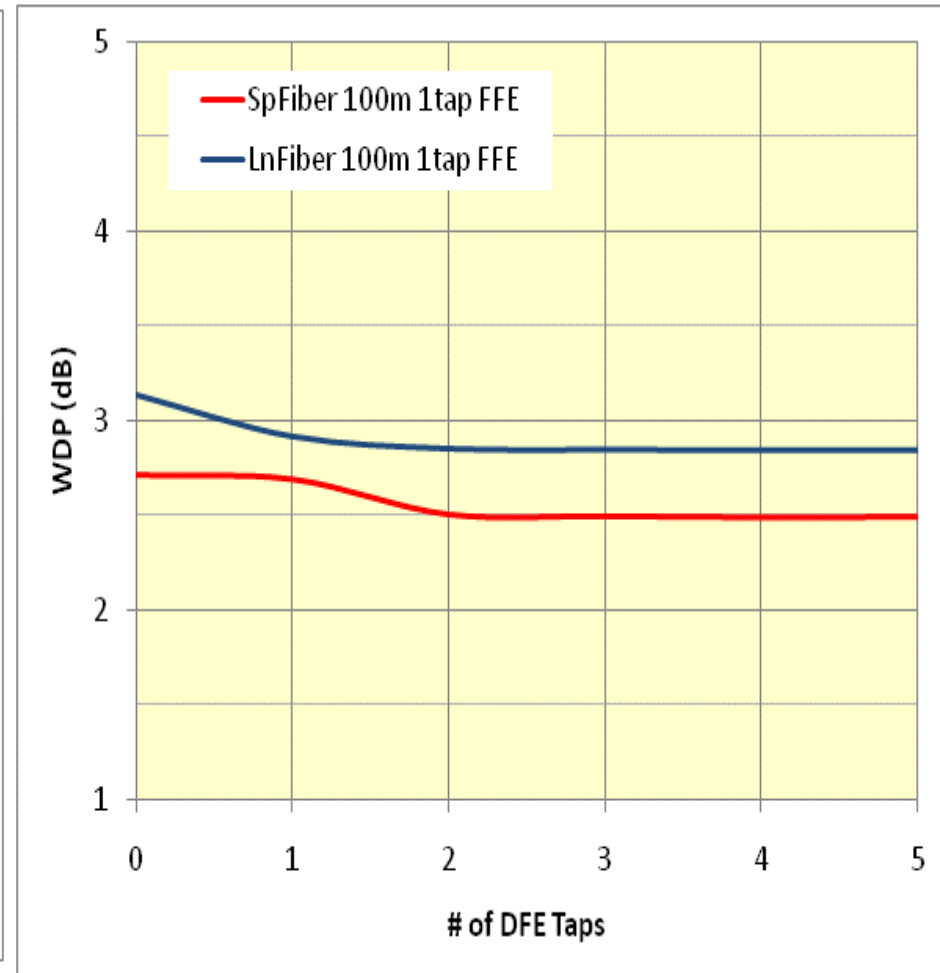
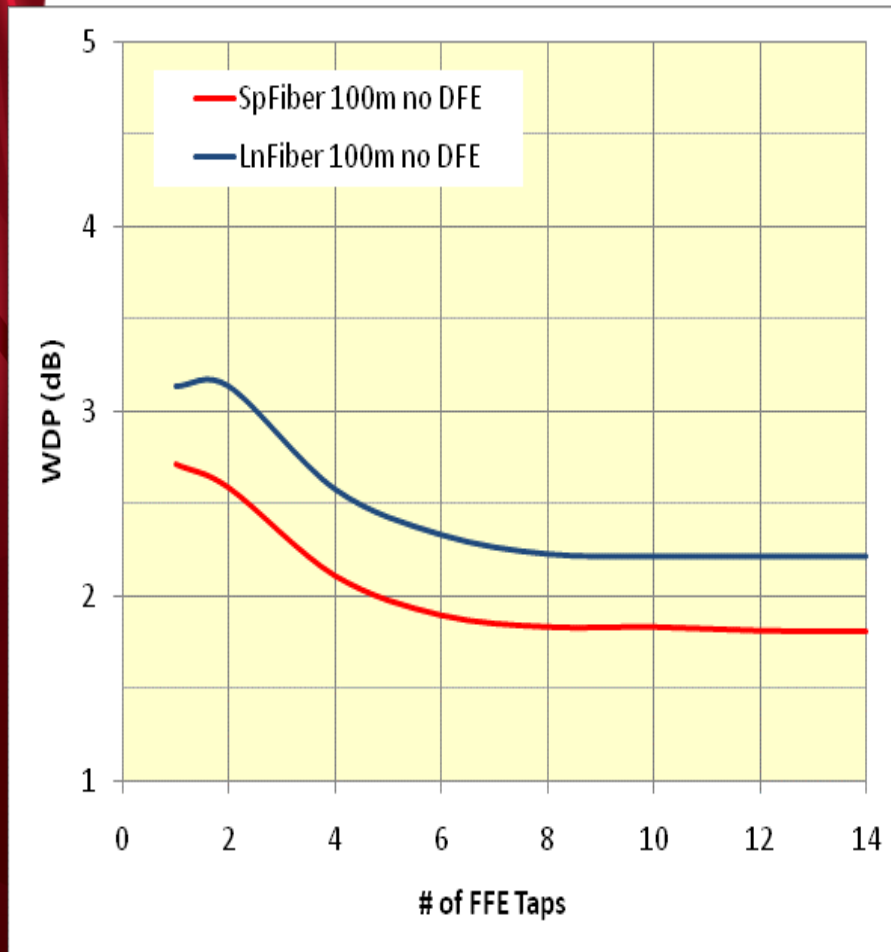
# Link Penalty With FFE and Varying DFE

- For linear fiber model and spatial fiber model
  - The spatial fiber model parameters chosen is not given us worst case response



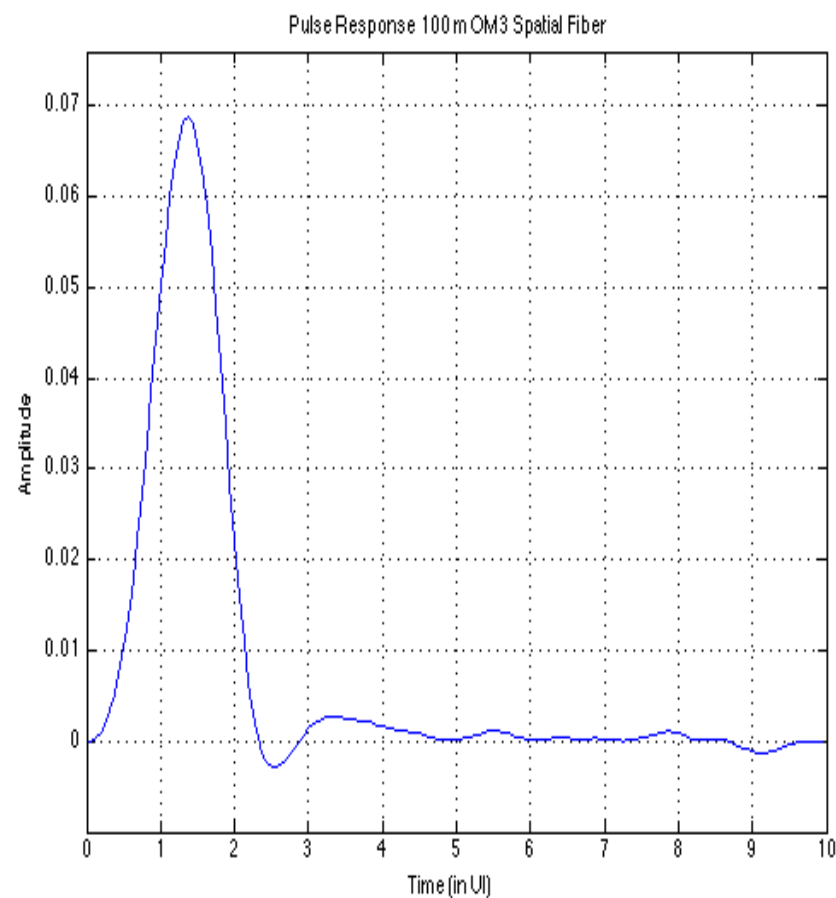
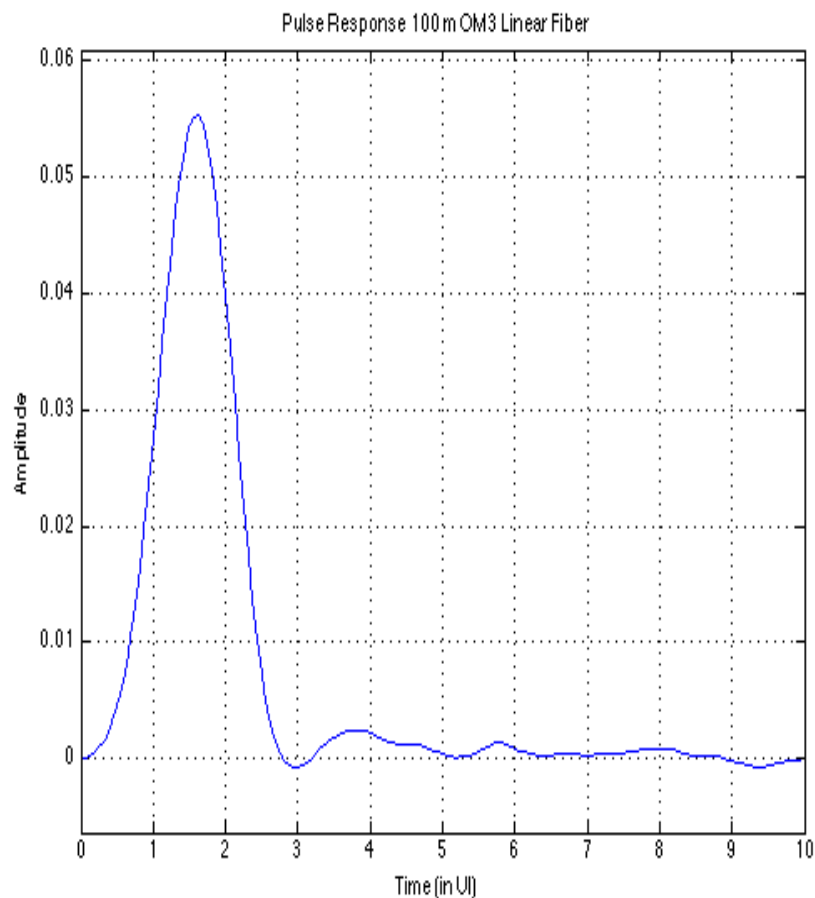
# Link Penalty Without FFE or DFE for 100 m Link

- Link penalty indicate DFE does little for the optical channel



# Combined Link Pulse Response

- For linear fiber model and spatial fiber model





# Summary

- **Investigated 25.78 GBd VCSEL link based on rate equation with both linear fiber with 2000 MHz.km and spatial fiber model**
  - No amount of link modeling regardless how complex can replace actual measured data specially when the link is dominated by the VCSEL response
  - 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, we encourage VCSEL/XCVR manufacture to supply captured waveform to the study group
- **As expected VCSEL is the largest source of optical penalty with ~ 2.5 dBo**
- **The spatial fiber model used here has higher BW than linear fiber model with 2000 MHz.Km**
- **As expected due to some pre-cursor ISI, the DFE is not helpful in equalizing the optical links that we have studied so far**
- **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**
- **Next step is to investigate fibers with different modal profile as well as cascading the results with cPPI-4 channel to study feasibility of unretimed.**