Simulations and Spreadsheet Link Model of 25.78G VCSEL Link

IEEE 100GNGOPTX Study Group

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Kona

Overview

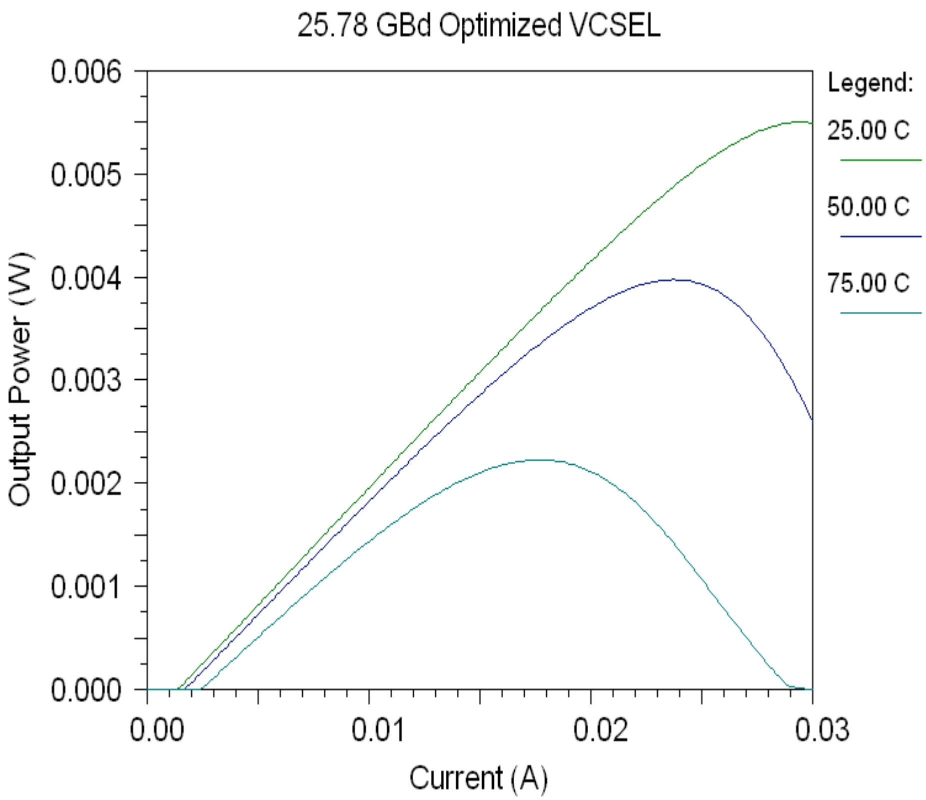
- 25-28G link performance are dominated by the VCSEL and receiver BW
  - For this reason we start with spatial rate equation model of VCSEL in time time domain to study the link
  - For detail result see ghiasi_02_1111
- An accurate link model is needed to investigate if a moderate size equalizer can extend link distance at 25.78 GBd 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
- Most results shown are for 25.78 GBd which has about 1 dBo less penalty than if the link operated at 28.05 GBd
  - Specific test cases could be simulated.

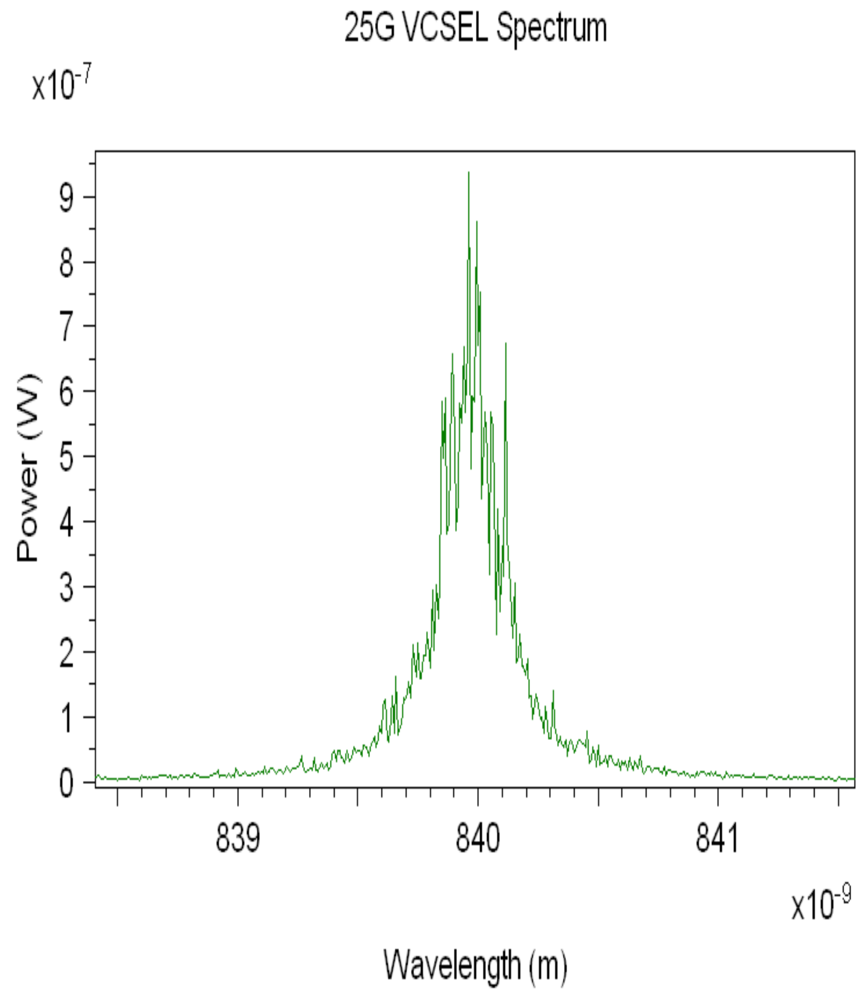
VCSEL and Link Model

- 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

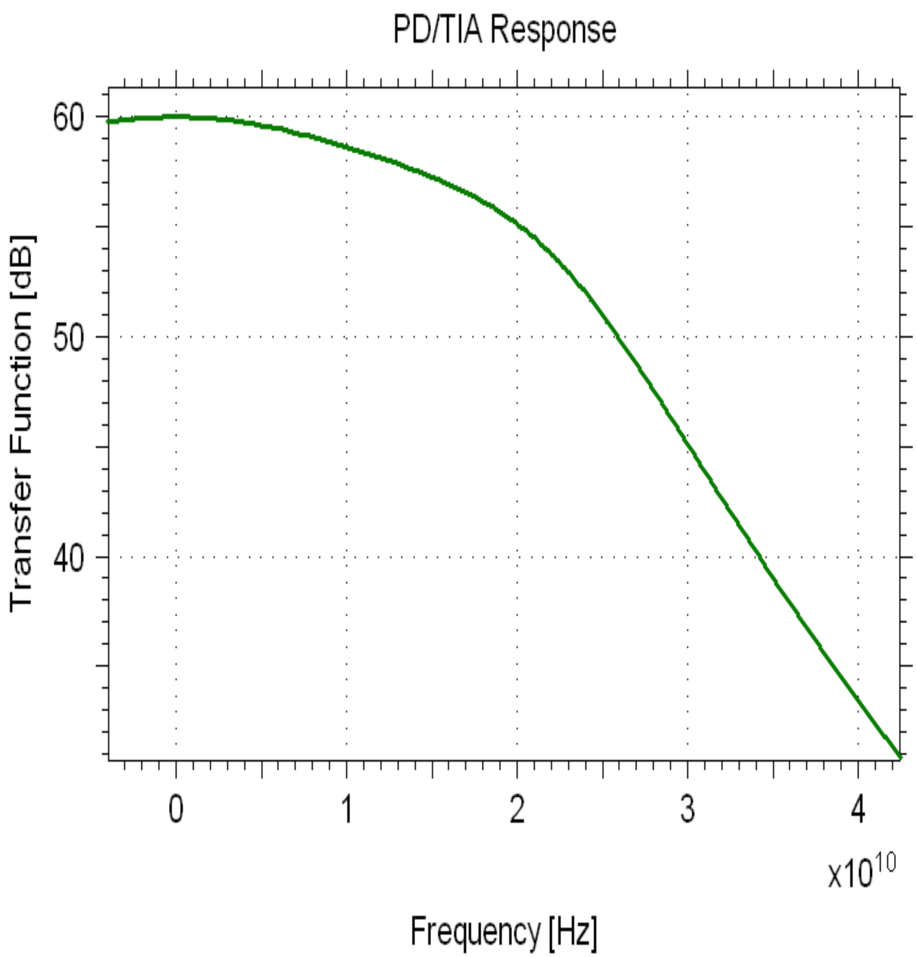
- Model include thermal effects
  - Spectral width was further expanded by optical phase noise to get FWHM=0.6 nm

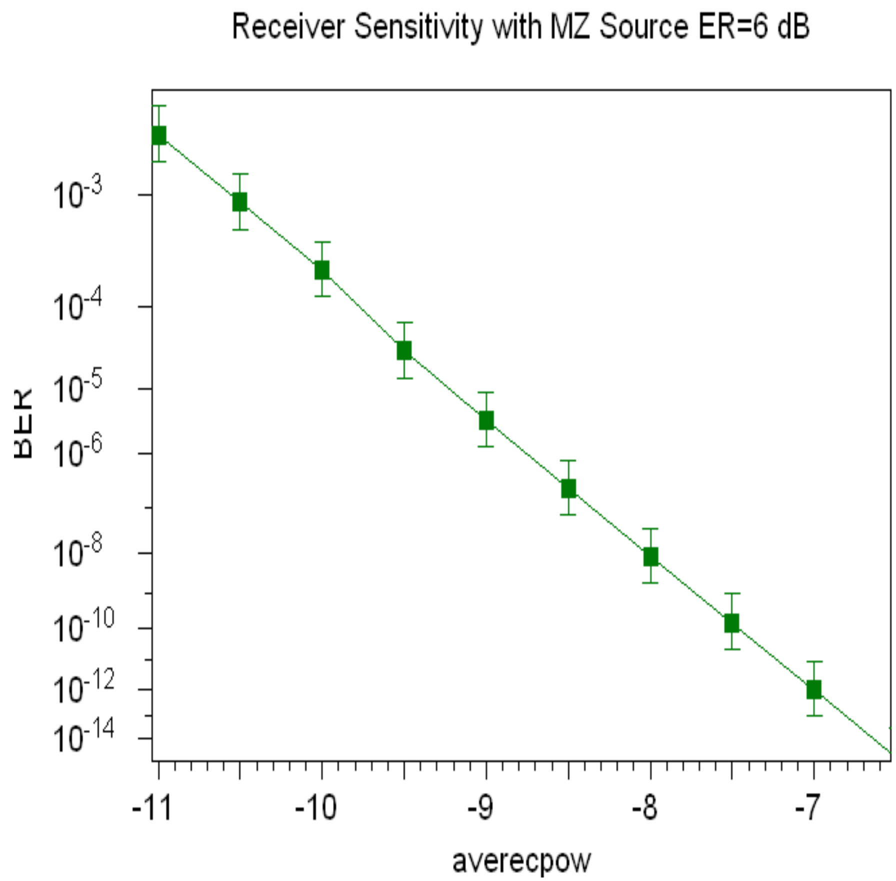




PIN/TIA

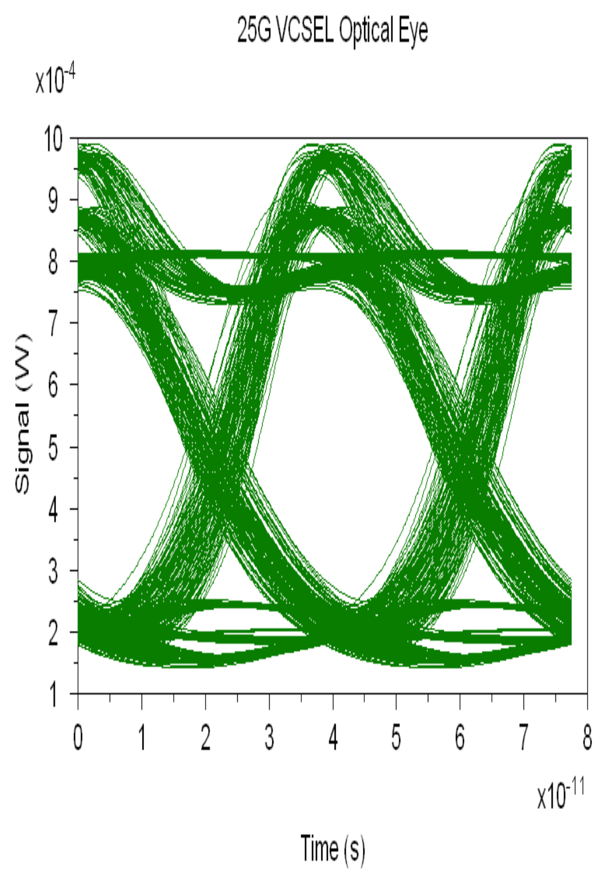
- TIA has TZ=1 kΩ, with BW of 15.75 GHz and sensitivity of -7 dBm with MZ source with ER=6 dB

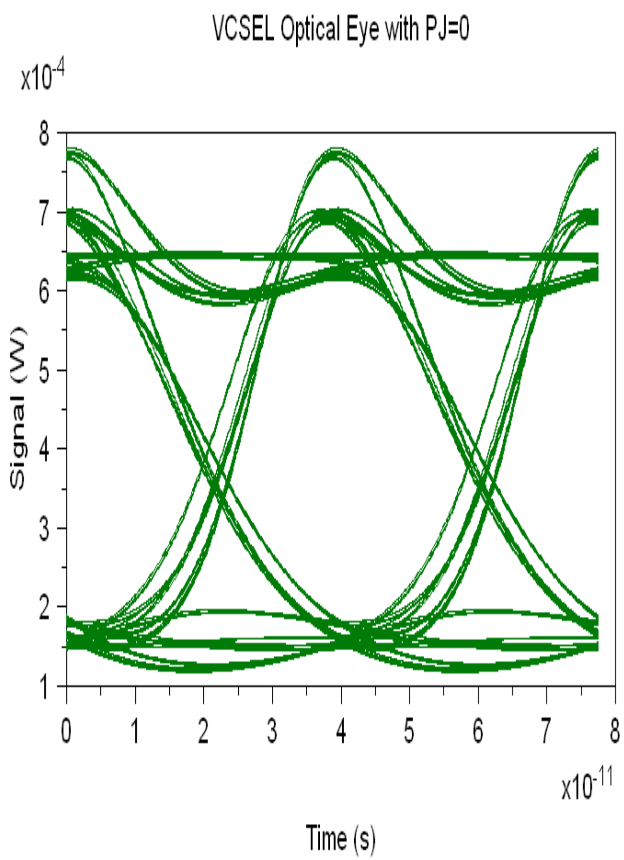


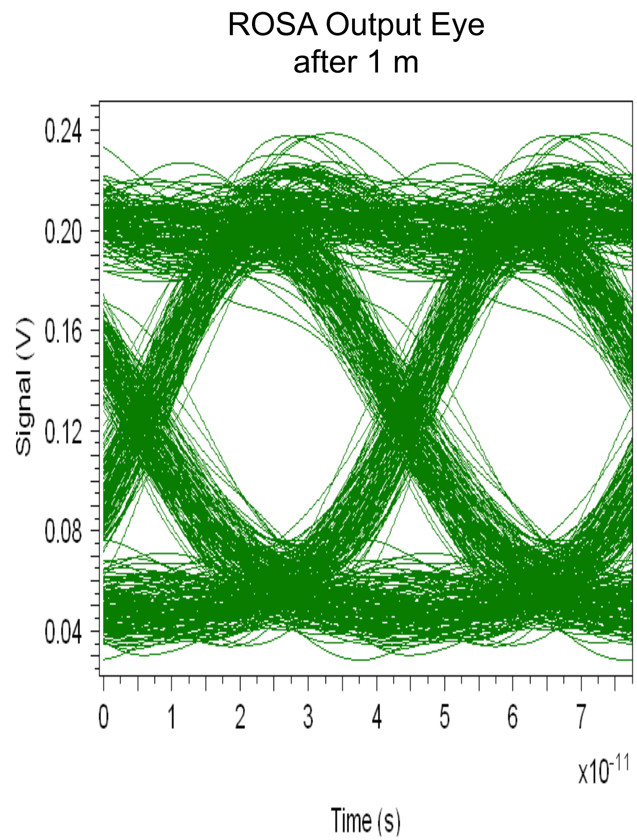


VCSEL Optical Eyes and Back to Back to Back Eye at 25.78 GBd

- 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

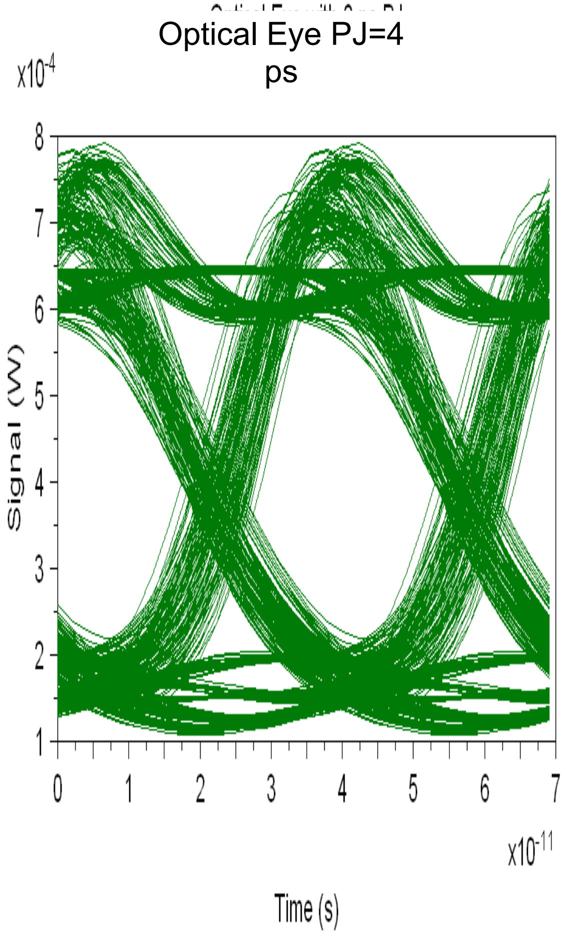


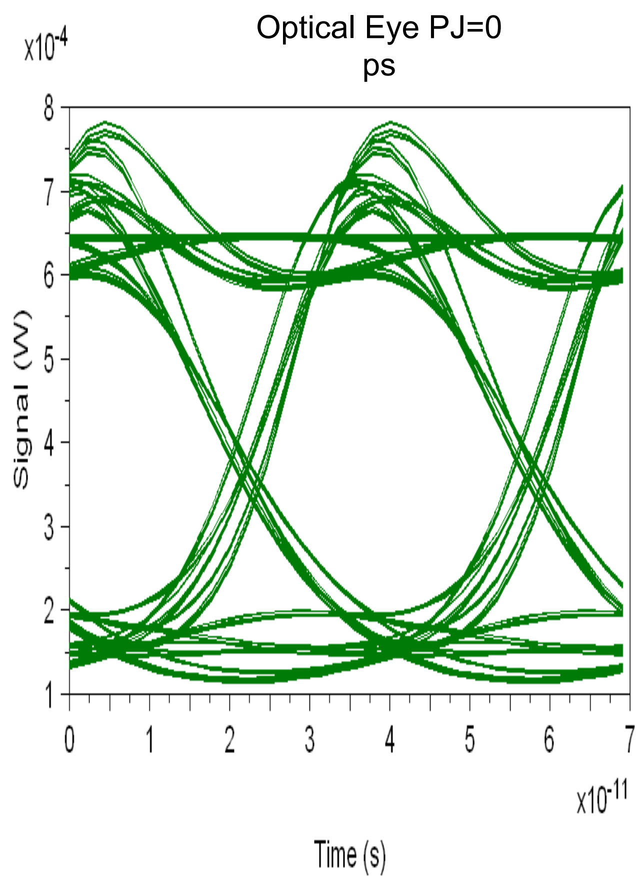


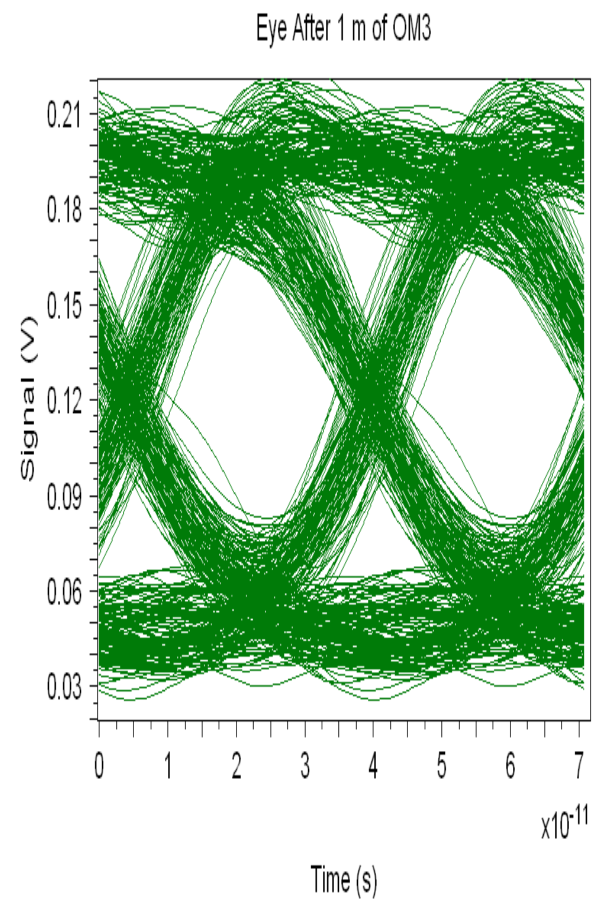


VCSEL Optical Eyes and Back to Back to Back Eye at 28.05 GBd

- 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

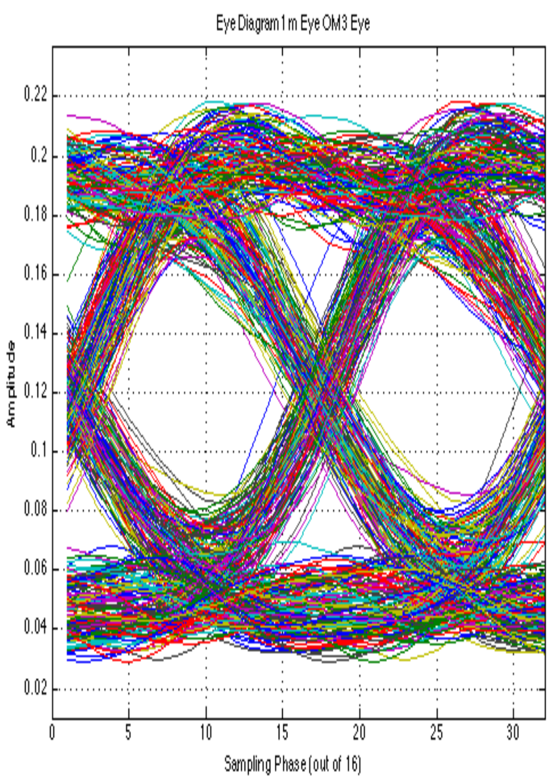


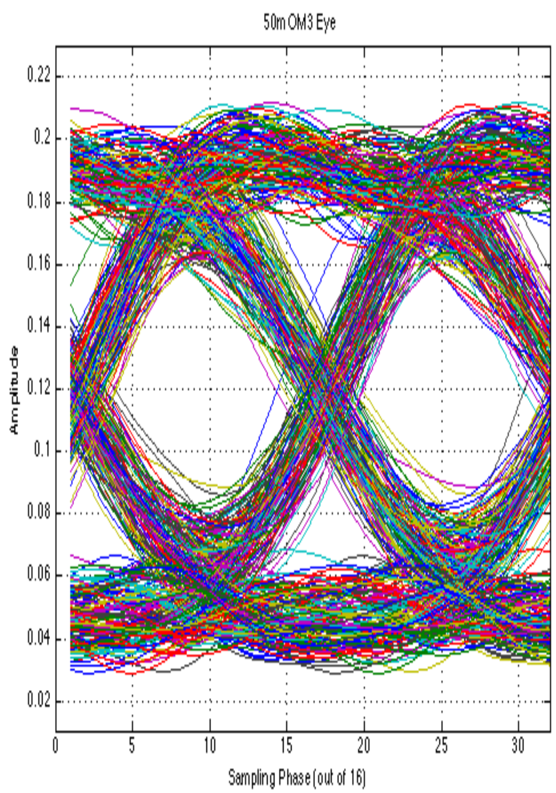


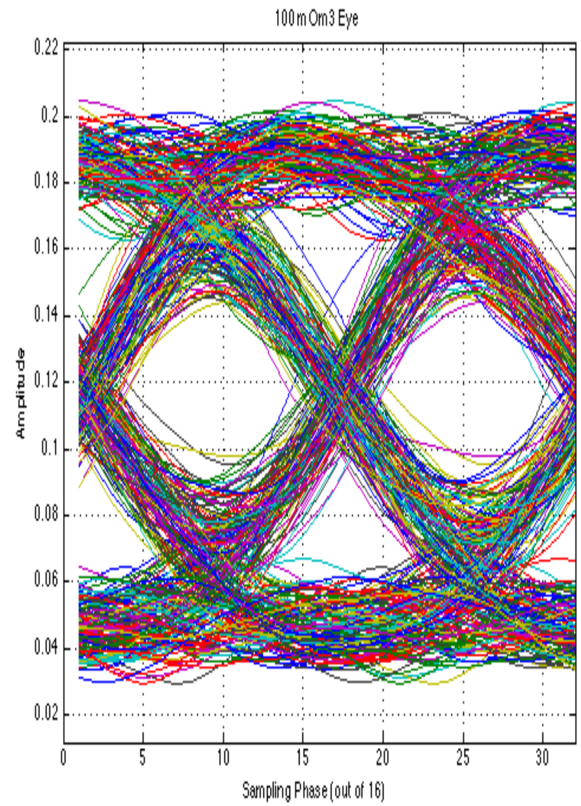


Far End Eye Diagram at 28.05 GBd

- For linear fiber model 1, 50, 100 m OM3

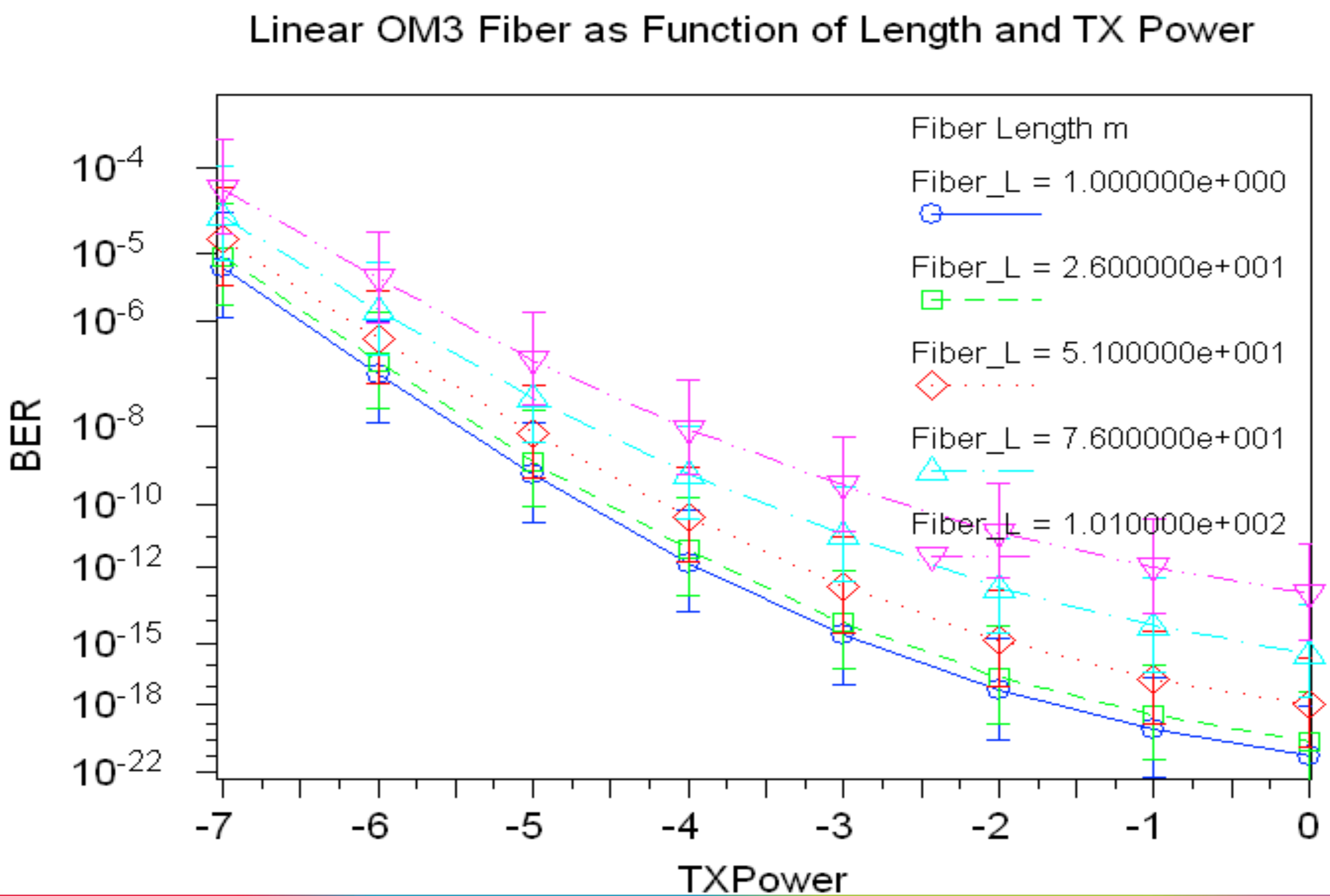






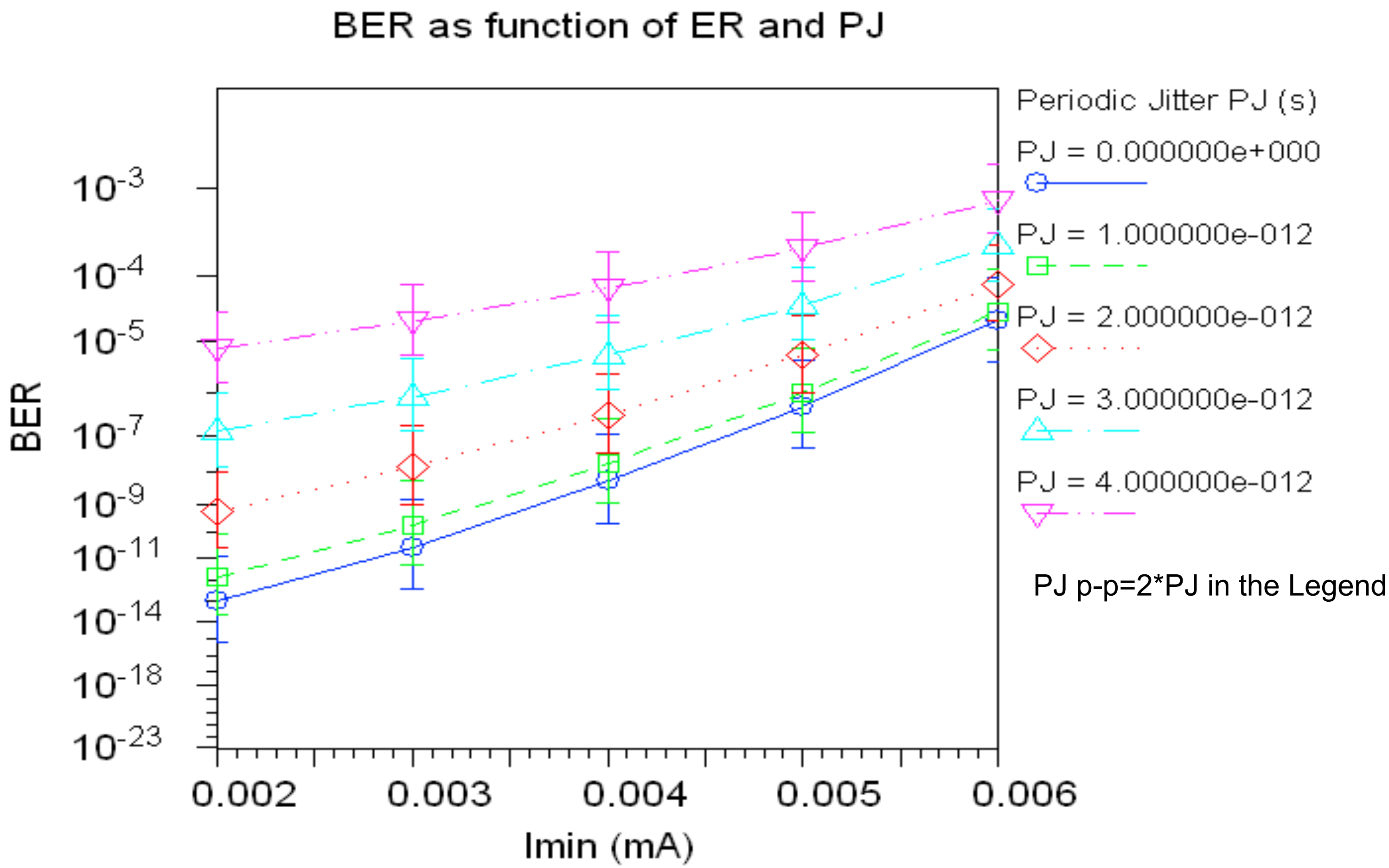
BER Plot for Linear OM3 Fiber Model

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



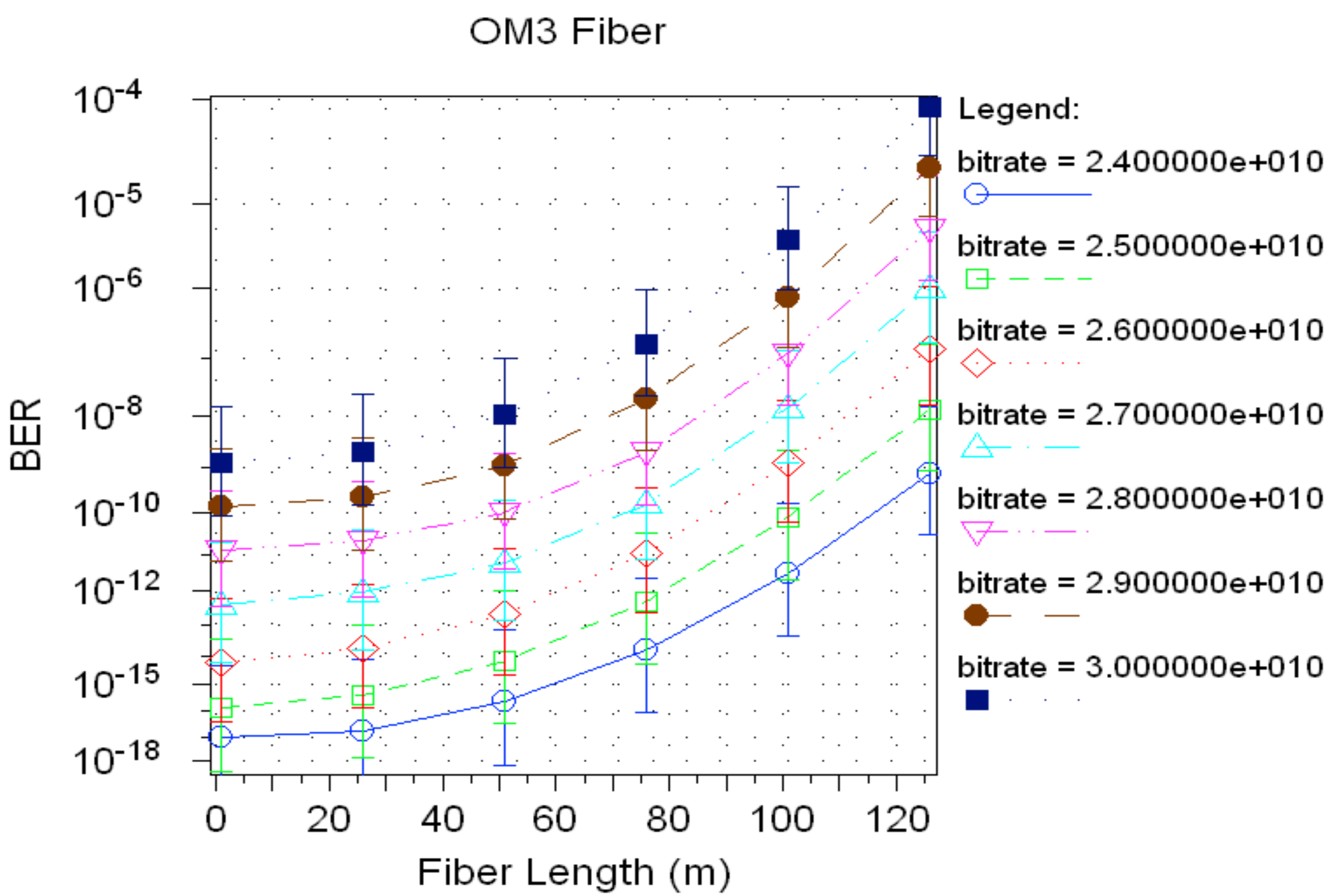
Sensitivity as Function of PJ and ER at 100 m and – 3 dBm for Linear Fiber

- 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



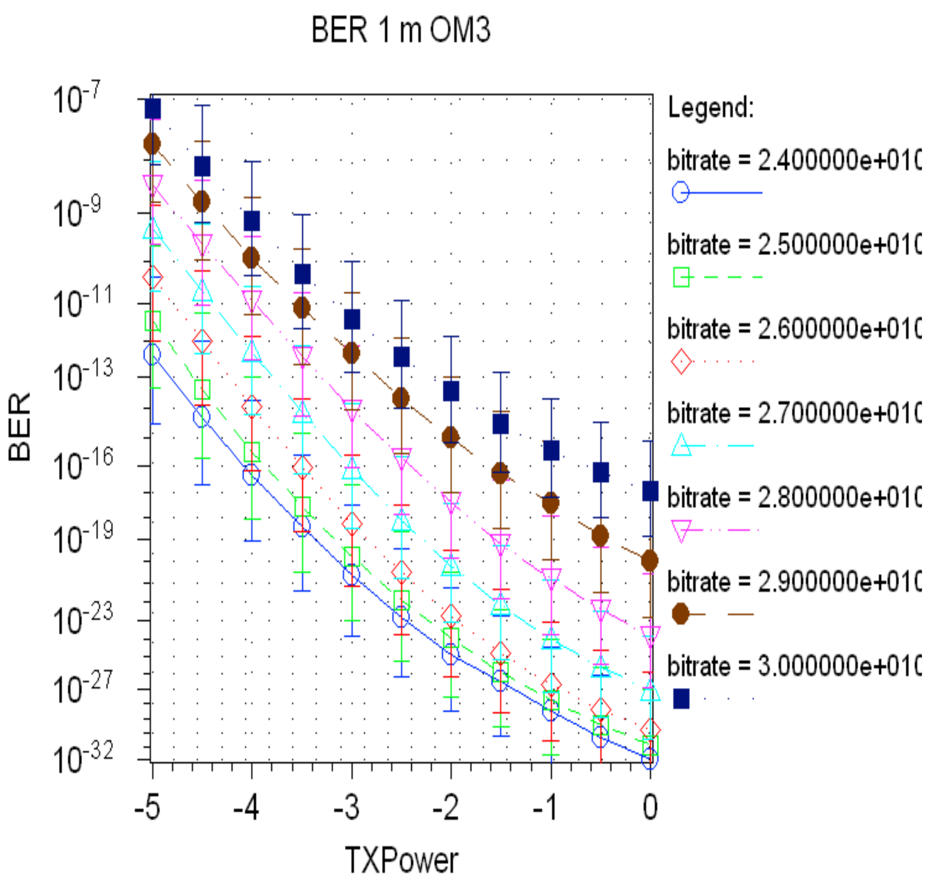
BER As Function of Buadrate and Length

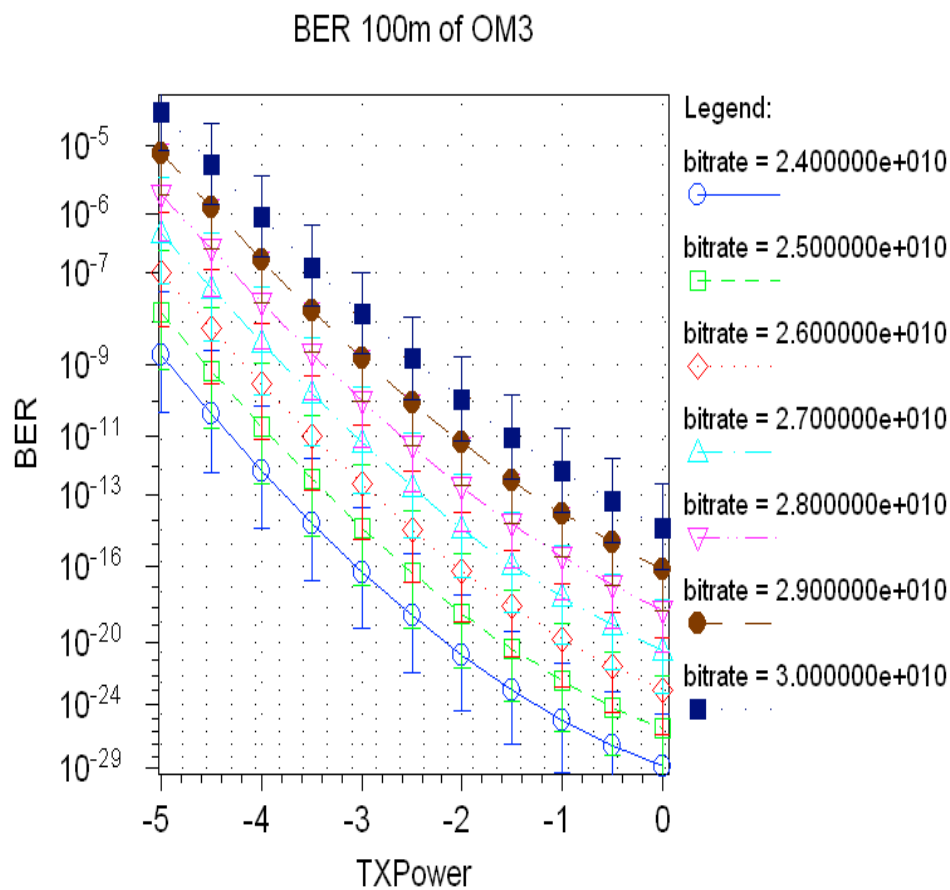
- Operating the link 28G B2B is equivalent to operating the link at 25.78G 75 m of OM3



Path Penalty as Function of Buadrate

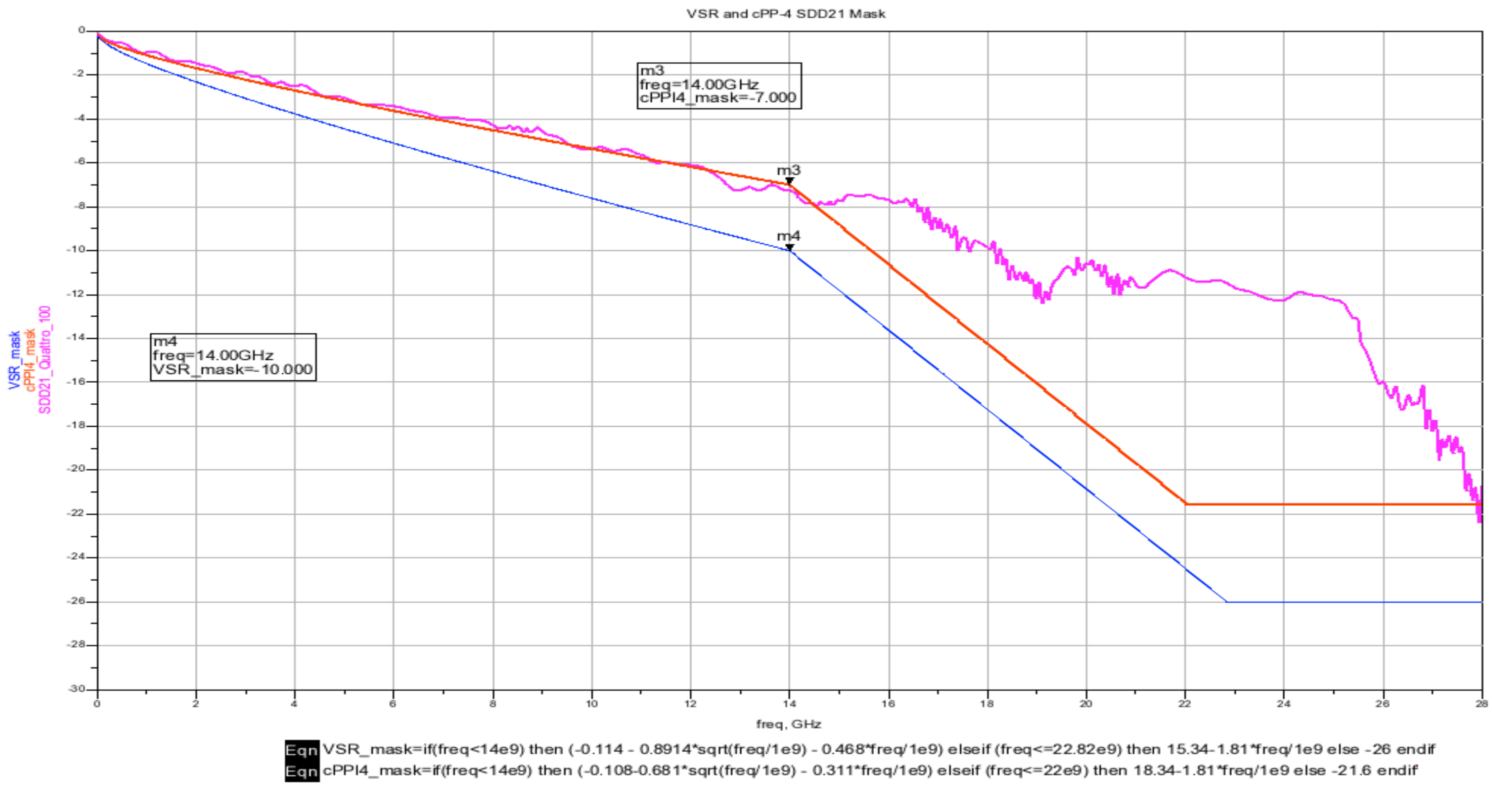
- Going from 25.78 GBd to 28.05 GBd there is about 1 dBo penalty

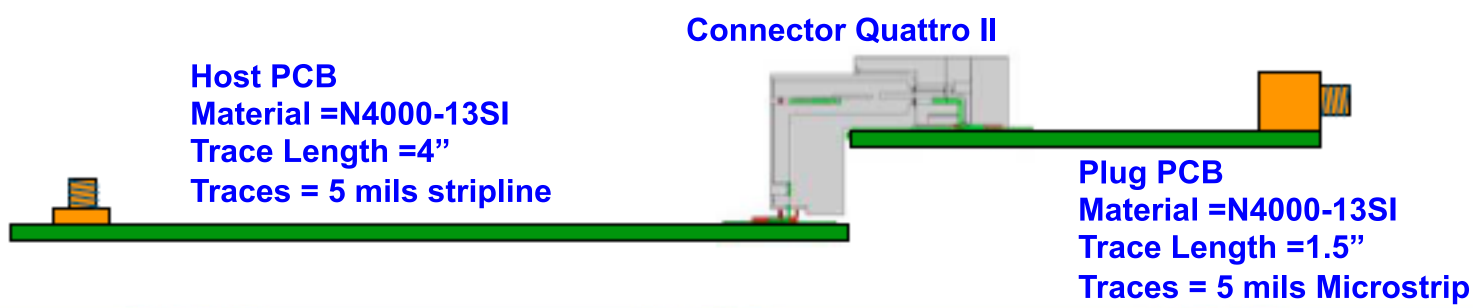




cPPI-4 Channel Based on TE Quattro II

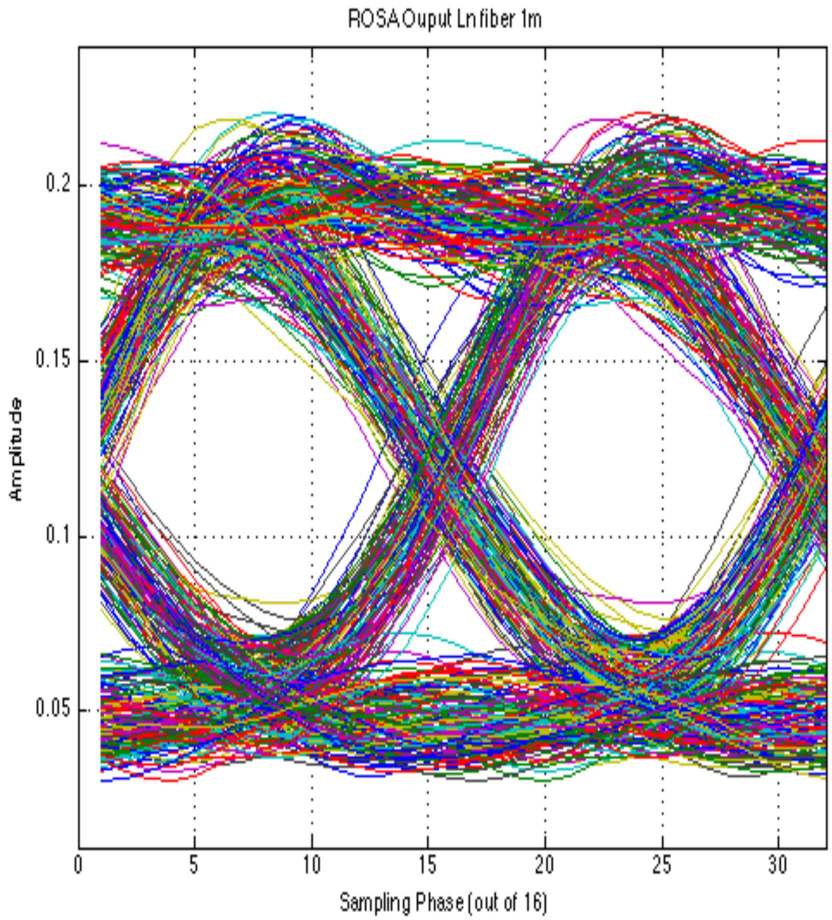
- VSR mask also shown

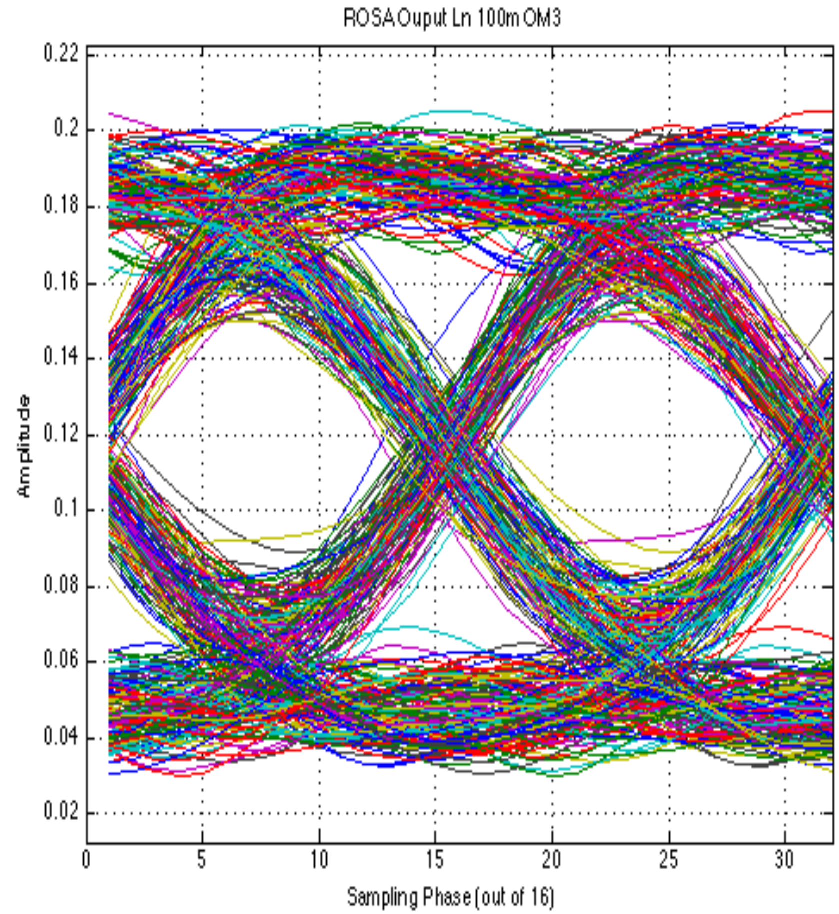




ROSA Output Linear Fiber Model

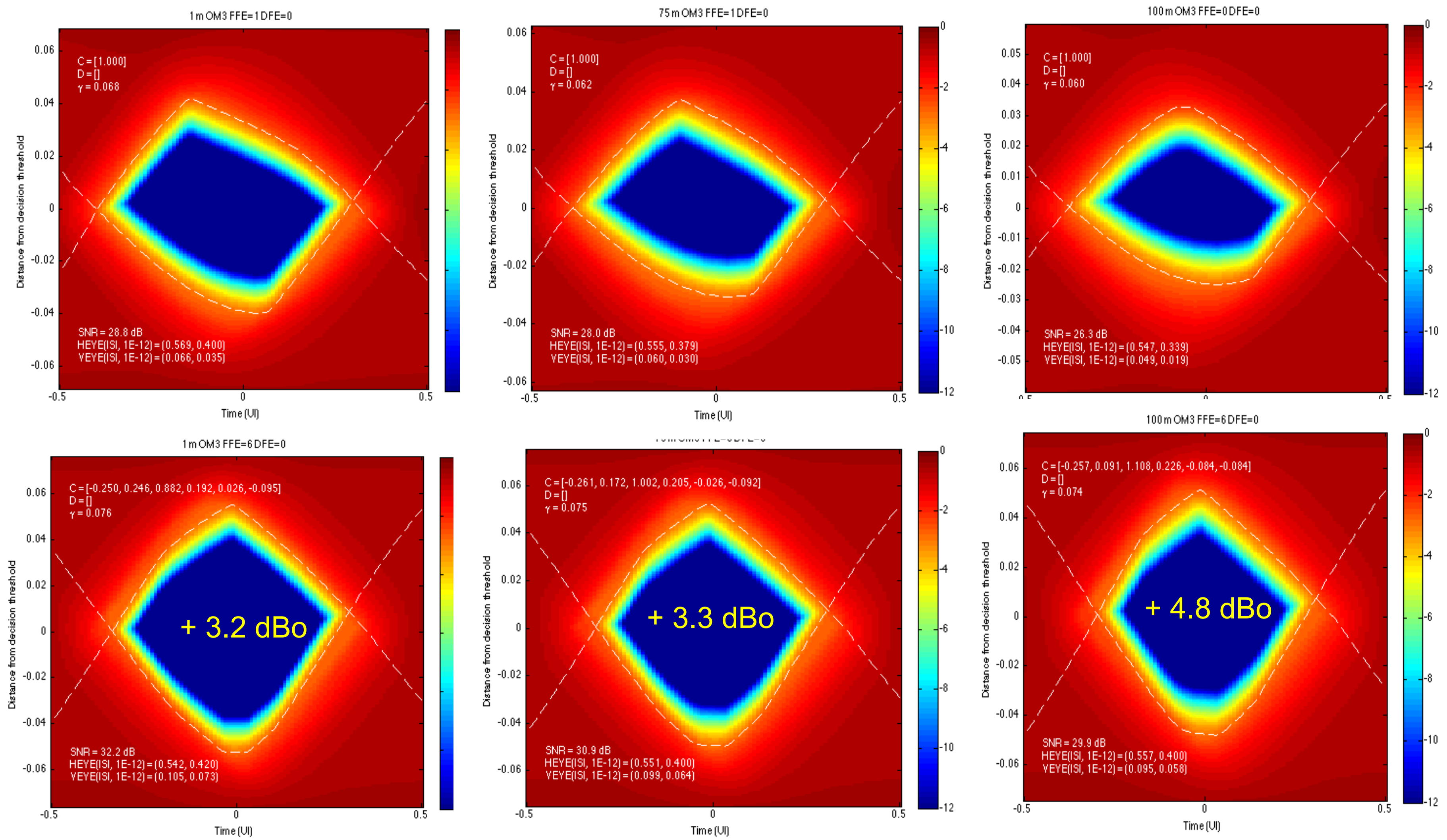
- After 1 m and 100 m of OM3 fiber





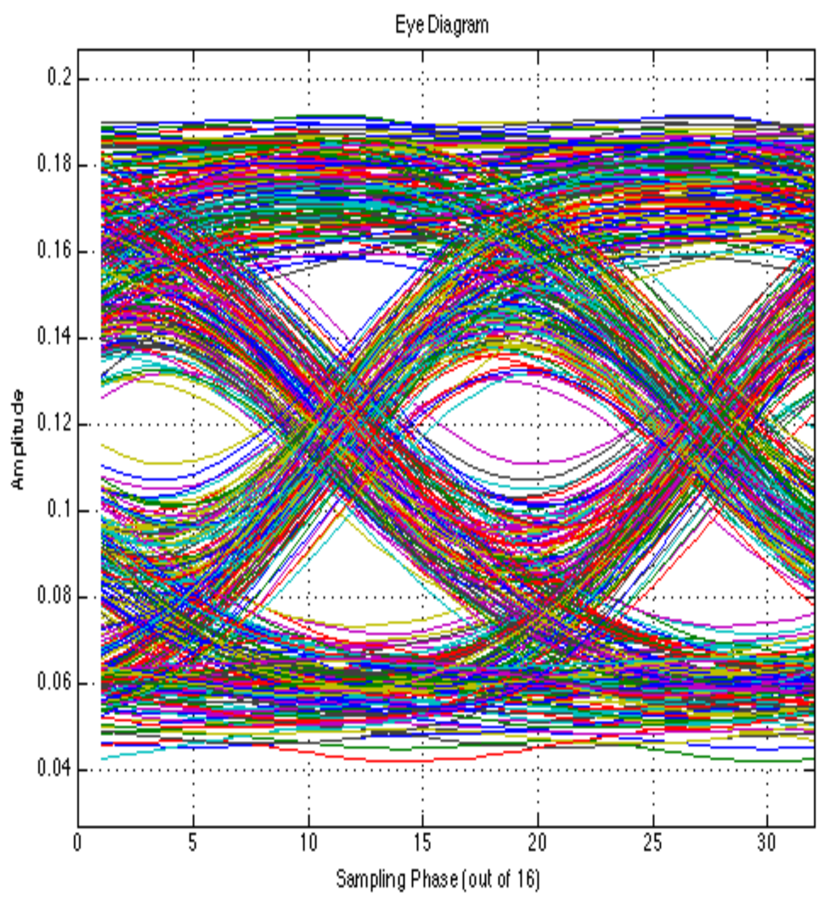
TP3 Eye Without EQ and 6 T/2 FFE after 1 m, 75 m, and 100 m of OM3

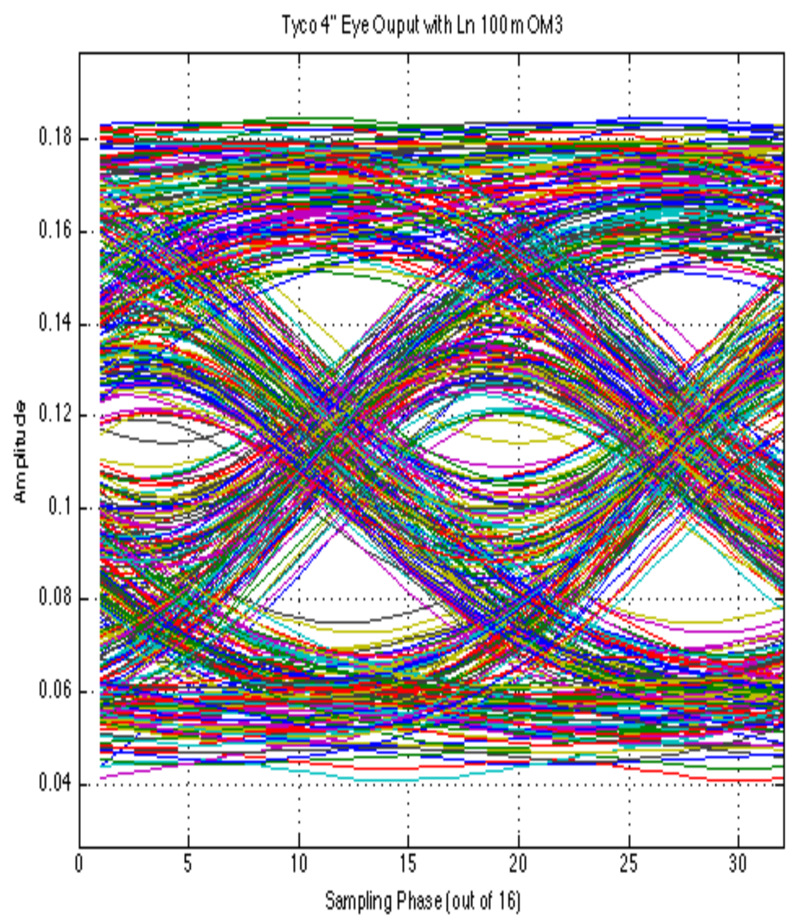
- At 100 m EQ increases the eye opening increases by +4.8 dBo @1E-12



TP5 Eye for the Linear Fiber Model

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

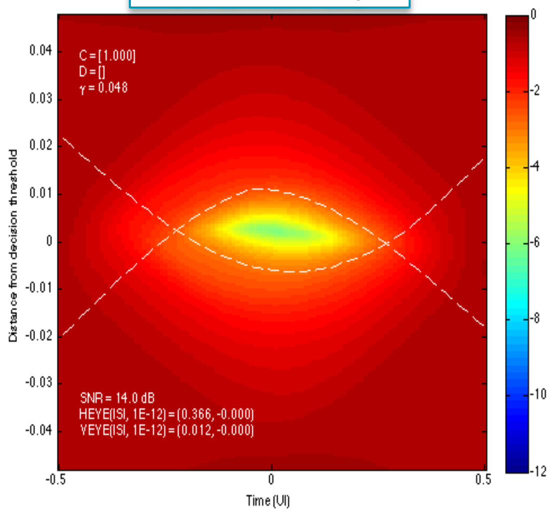




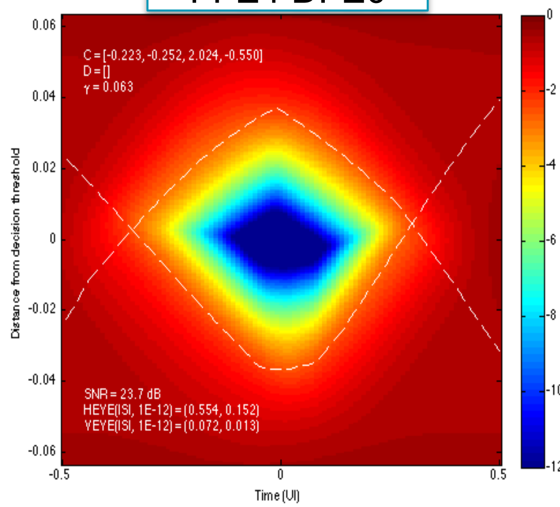
TP5 Eye with 4” host PCB and 1 m OM3

- At – 3 dBm input with 1kΩ TIA TP5 eye opening at 1E-12 is 32 mV with 6 T/2 FFE+3DFE

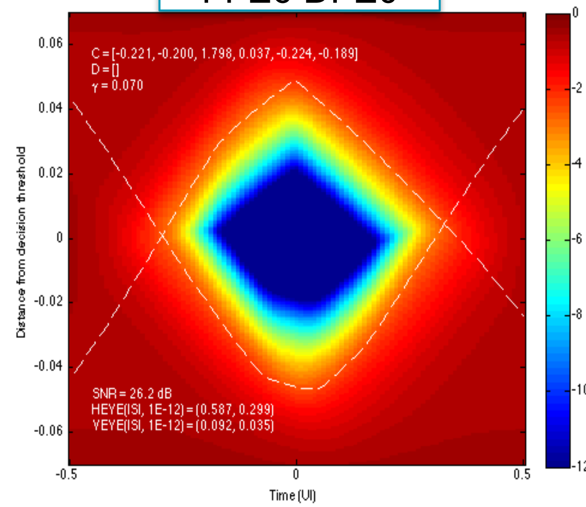
FFE1 DFE0



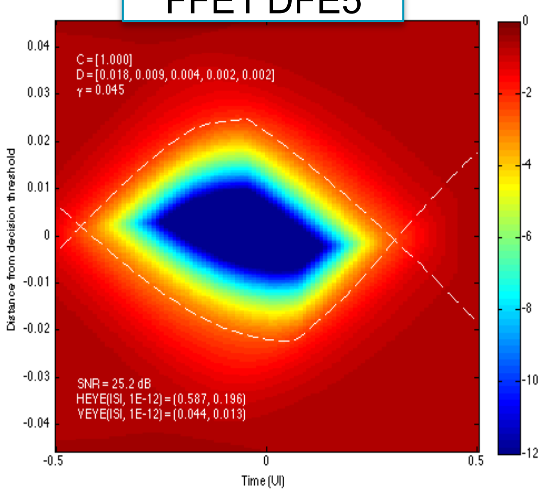
FFE4 DFE0



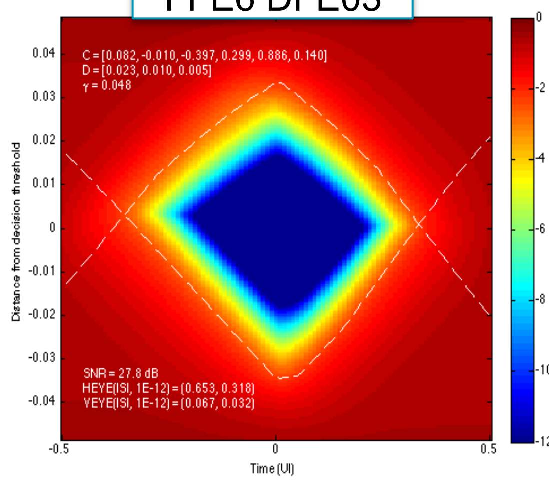
FFE6 DFE0



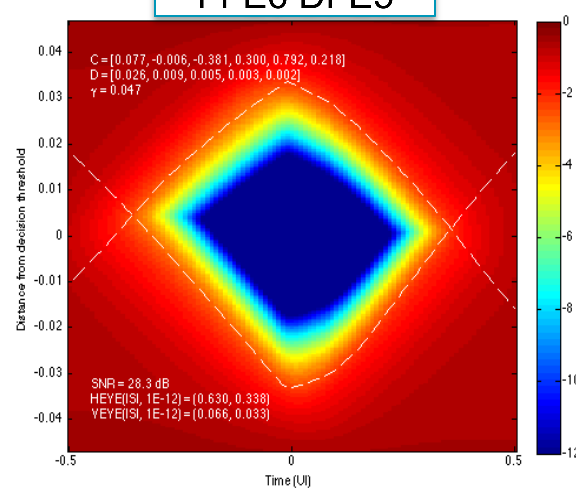
FFE1 DFE5



FFE6 DFE03

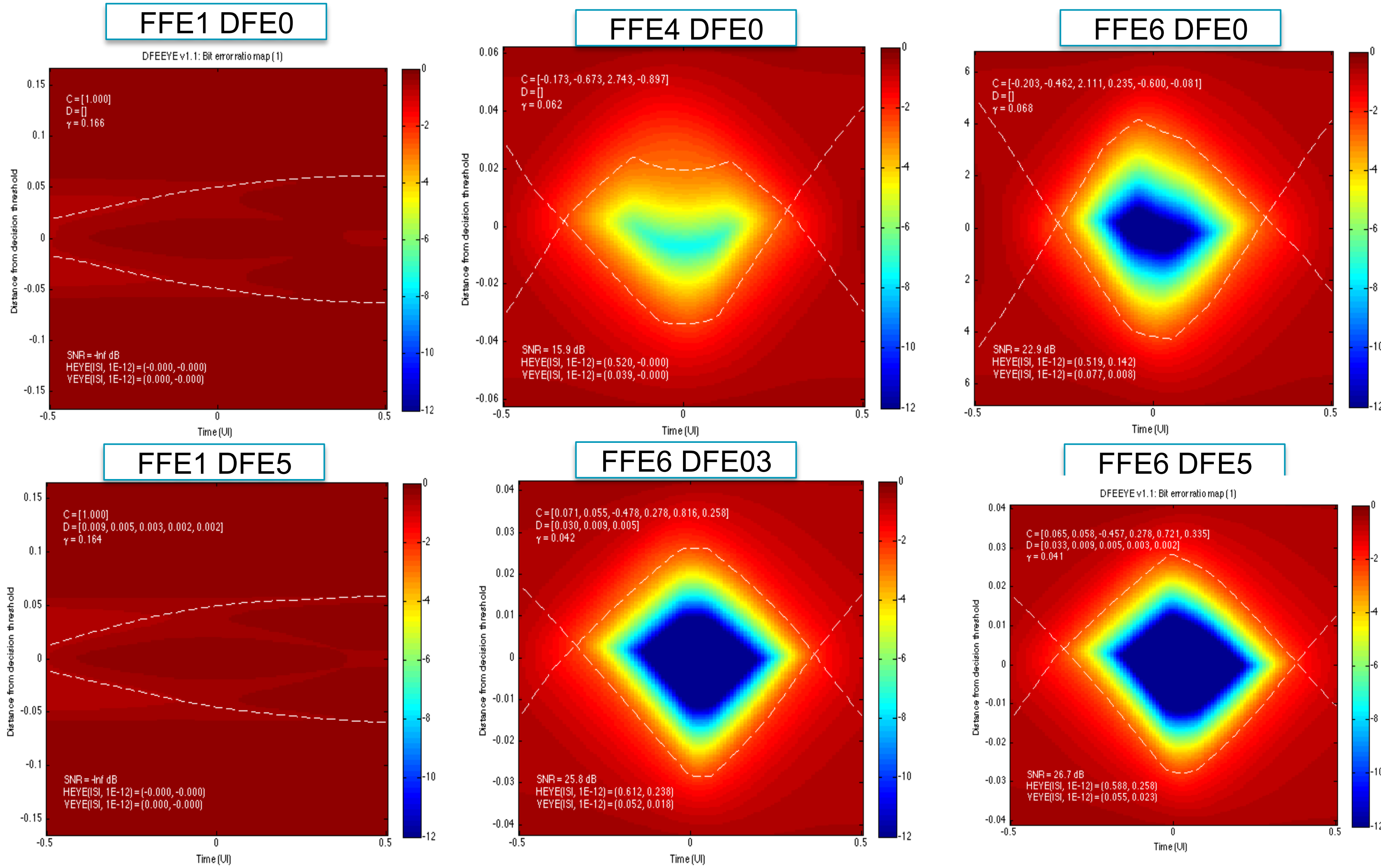


FFE6 DFE5



TP5 Eye with 4” host PCB and 100 m OM3

- At – 3 dBm input with 1kΩ TIA TP5 eye opening at 1E-12 is 18 mV with 6 T/2 FFE+3DFE



Some Background on Mode Partition Noise

- Starting with David Cunningham presentation T11 12-042v1
  - Assuming a Gaussian shape optical power spectrum one may approximate the σ_{mpn} as:

$$\sigma_{mpn} = \frac{k_{OMA}}{\sqrt{2}} \cdot \left[1 - e^{\left(-\beta^2\right)} \right]$$

Where K_{OMA} is the MPN coefficient and β is given by:

$$\beta = \pi \cdot B \cdot D \cdot L \cdot \sigma_{\lambda} \cdot \gamma$$

Where B is the bandwidth, D is the chromatic dispersion, L length, σ_{λ} is RMS spectral width, and γ is is a constant introduced to account for effective increase or decrease of delay due to DMD profile of the fiber.

Then the power penalty due to mode partition noise is calculated using following equation:

$$P_{mpn} = 10 \cdot \log \left(\frac{1}{\sqrt{1 - Q^2 \cdot \left(\sigma_{mpn}\right)^2}} \right)$$

In the spreadsheet currently B=1/(T-DCD) and how can MPN increases if DCD is increased
Or why should the MPN increases by just toggling the laser faster when it never reaches steady state!
A more suitable definition of B in calculation of b is the effective laser BW which can be derived from10-90% rise time as 0.35/tr.

FC 32GFC Spreadsheet Modified for 25.78 GBd OM3 Fiber

Spreadsheet by David Cunningham, Avago Technologies									Rev.	#REF!	This file		#REF!		of	#REF!	
Basics Input=	Bold		Ts(20-80)	24	ps	Case: 850nm serial	newMMF		Attenuation=	3.5	dB/km	Model/format rev	#REF!		of	#REF!	
Q=	7.04		Ts(10-90)	36	ps	*Target* Target reach	0.10	km	*Fiber* at	850	nm	NomSens OMA	-8.50	dBm	Margin	#NUM!	dB at
Base Rate=	25781.3	MBd	RIN(OMA)	-131	dB/Hz	*and* L_start=	0.03	km	C_att=	1.00		*Receiver* Refl Rx	-12	dB	*Answer!*		0.1 km
Transmitter			RIN at MinER	-135.0	dB/Hz	*graph* L_inc=	0.01	km	Attenuation=	3.62	dB/km	Rec_BW=	15,469	MHz	Test Rx BW	15,469	MHz
Wavelength Uc	840	nm	RIN_Coef=	0.70		Power Budget P=	8.50	dB	at	840	nm	c_rx	329	ns.MHz			
Uw (see notes)	0.50	nm	Det.Jitter	4.28	ps inc. DCD	Connections C	1.50	dB	Disp. min. Uo=	1316	nm	T_rx(10-90)	21.3	ps	Test Source ER=		
Tx pwr OMA=	0.00	dBm	DCD_DJ=	4.28	ps TP3	Pwr.Bud.-Conn.Loss	7.00	dB	Disp. So=	0.10275	ps/nm^2*km	TP4 Eye	8	ps	*Test Tx*	6.5	dB
Min. Ext Ratio=	6.43	dB	Effect. DJ=	0.00	(UI) ex DCD	C1=	480	ns.MHz	Disp. D1=	-108.41	ps/(nm.km)	Opening		(=Tx eye	TestERpen.	1.98	dBo
"Worst"ave.TxPwr	-1.0	dBm	MPN k(OMA)	0.3		Reflection Noise factor	0	no units	γ =	1.0		RMS Baseline wander SD	0.013	fraction of 1/2 eye			
Ext. ratio penalty	2.01	dBo	Tx eye height	29.5%		Effective Rate	28977	MBd	(not in use)	10		STD			V.E.C.P.	6.24	dBo
Tx mask X1=	0.3	UI	Refl Tx	-12	dB	Tb_eff=	35	ps	BWm=	2000	MHz*km	P_BLW(no ISI)	0.02	dB			
X2=	0.4	UI	ModalNoisePen	0.3	dB	Effective Rec Eye	0.22	UI	Eff. BWm=	2.0E+03	MHz*km	P_BLW	0.02	dB			
Y1=	0.25		Tx mask top	0.2	UI												

L (km)	Patt (dB)	Ch IL (dB)	D1.L ps/nm	D2.L ps/nm	BWcd (MHz)	effBWm (MHz)	Te (ps)	Tc (ps)	Pisi central J=0, dB	P Eye corners (dB)	P_DJ central (dB)	P_DJ corners (dB)	Preflection central (dB)	Beta	SDmpn	Pmpn (dB)	Prin (dB)	Pcross central (dB)	Ptotal central (dB)	<Ptotal corners (dB)	LP Pen central (dB)	10GbE Method Margin (dB)	Stressed Rx sens OMA central (dBm)
0.002	0.01	1.51	-0.22	0.00	2E+06	1.0E+06	36	42	3.86	0.29	0.00	0.00		-0.01	0.00	0.00	1.00	-0.72	3.45	3.74	3.4	3.6	#NUM!
0.025	**0.09**	**1.59**	**-2.7**	**0.00**	**137,992**	**80,000**	**37**	**43**	**4.00**	**0.29**	**0.00**	**0.00**	**0**	**-0.12**	**0.00**	**0.00**	**1.00**	**0.40**	**5.8**	**6.1**	**5.7**	**1.2**	**#NUM!**
0.03	0.11	1.61	-3.3	0.00	114,994	66,667	37	43	4.06	0.29	0.00	0.00	0	-0.15	0.00	0.00	1.01	0.41	5.9	6.2	5.8	1.1	#NUM!
0.035	0.13	1.63	-3.8	0.00	98,566	57,143	38	43	4.13	0.29	0.00	0.00	0	-0.17	0.01	0.00	1.03	0.43	6.0	6.3	5.9	1.0	#NUM!
0.04	0.14	1.64	-4.3	0.00	86,245	50,000	38	44	4.22	0.30	0.00	0.00	0	-0.20	0.01	0.01	1.04	0.45	6.2	6.5	6.0	0.8	#NUM!
0.045	0.16	1.66	-4.9	0.00	76,662	44,444	39	44	4.31	0.30	0.00	0.00	0	-0.22	0.01	0.01	1.07	0.48	6.3	6.6	6.2	0.7	#NUM!
0.05	**0.18**	**1.68**	**-5.4**	**0.00**	**68,996**	**40,000**	**39**	**44**	**4.42**	**0.30**	**0.00**	**0.00**	**0**	**-0.25**	**0.01**	**0.02**	**1.10**	**0.51**	**6.5**	**6.8**	**6.35**	**0.5**	**#NUM!**
0.055	0.20	1.70	-6.0	0.00	62,724	36,364	39	45	4.54	0.30	0.00	0.00	0	-0.27	0.02	0.02	1.13	0.56	6.8	7.1	6.6	0.2	#NUM!
0.06	0.22	1.72	-6.5	0.00	57,497	33,333	40	45	4.67	0.30	0.00	0.00	0	-0.30	0.02	0.03	1.18	0.62	7.0	7.3	6.8	0.0	#NUM!
0.065	0.24	1.74	-7.0	0.00	53,074	30,769	41	46	4.82	0.31	0.00	0.00	0	-0.32	0.02	0.05	1.23	0.71	7.3	7.6	7.1	-0.3	#NUM!
0.07	0.25	1.75	-7.6	0.00	49,283	28,571	41	46	4.97	0.31	0.00	0.00	0	-0.35	0.02	0.06	1.30	0.82	7.7	8.0	7.5	-0.7	#NUM!
0.075	**0.27**	**1.77**	**-8.1**	**0.00**	**45,997**	**26,667**	**42**	**47**	**5.15**	**0.31**	**0.00**	**0.00**	**0**	**-0.37**	**0.03**	**0.08**	**1.39**	**0.98**	**8.2**	**8.5**	**7.9**	**-1.2**	**#NUM!**
0.08	0.29	1.79	-8.7	0.00	43,123	25,000	43	48	5.33	0.32	0.00	0.00	0	-0.39	0.03	0.10	1.50	1.22	8.7	9.1	8.5	-1.7	#NUM!
0.085	0.31	1.81	-9.2	0.00	40,586	23,529	43	48	5.53	0.33	0.00	0.00	0	-0.42	0.03	0.13	1.64	1.58	9.5	9.8	9.2	-2.5	#NUM!
0.09	0.33	1.83	-9.8	0.00	38,331	22,222	44	49	5.75	0.33	0.00	0.00	0	-0.44	0.04	0.16	1.82	2.25	10.6	10.9	10.3	-3.6	#NUM!
0.095	0.34	1.84	-10.3	0.00	36,314	21,053	45	50	5.98	0.34	0.00	0.00	0	-0.47	0.04	0.20	2.06	3.91	12.8	13.1	12.5	-5.8	#NUM!
0.10	**0.36**	**1.86**	**-10.8**	**0.00**	**34,498**	**20,000**	**46**	**50**	**6.24**	**0.35**	**0.00**	**0.00**	**0**	**-0.49**	**0.05**	**0.24**	**2.38**	**#####**	**#NUM!**	**#NUM!**	**#NUM!**	**#NUM!**	**#NUM!**
0.105	0.38	1.88	-11.4	0.00	32,855	19,048	47	51	6.51	0.36	0.00	0.00	0	-0.52	0.05	0.29	2.86	#####	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!
0.11	0.40	1.90	-11.9	0.00	31,362	18,182	48	52	6.81	0.37	0.00	0.00	0	-0.54	0.05	0.34	3.65	#####	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!
0.115	0.42	1.92	-12.5	0.00	29,998	17,391	48	53	7.13	0.39	0.00	0.00	0	-0.57	0.06	0.40	5.36	#####	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!
0.12	0.43	1.93	-13.0	0.00	28,748	16,667	49	54	7.47	0.40	0.00	0.00	0	-0.59	0.06	0.47	#NUM!	#####	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!
0.15	**0.54**	**2.04**	**-16.3**	**0.01**	**22,999**	**13,333**	**55**	**59**	**10.50**	**0.66**	**0.00**	**0.00**	**0**	**-0.74**	**0.09**	**1.09**	**#NUM!**	**#####**	**#NUM!**	**#NUM!**	**#NUM!**	**#NUM!**	**#NUM!**

32GFC Spreadsheet at 25.78 GBd OM3 Fiber with EFF BW

Spreadsheet by David Cunningham, Avago Technologies

Basics Input=	Bold		Ts(20-80)	24	ps	Case: 850nm serial	newMMF		Rev. #REF! This file	#REF!	of #REF!
Q=	7.04		Ts(10-90)	36	ps	*Target* Target reach	0.10	km	Attenuation= 3.5 dB/km	Model/format rev #REF!	of #REF!
Base Rate=	25781.3	MBd	RIN(OMA)	-131	dB/Hz	*and* L_start=	0.03	km	*Fiber* at 850 nm	NomSens OMA -8.50 dBm	Margin -5.48 dB at
Transmitter			RIN at MinER	-135.0	dB/Hz	*graph* L_inc=	0.01	km	C_att= 1.00	*Receiver* Refl Rx -12 dB	*Answer!* 0.1 km
Wavelength Uc	840	nm	RIN_Coef=	0.70		Power Budget P=	8.50	dB	Attenuation= 3.62 dB/km	Rec_BW= 15,469 MHz	Test Rx BW 15,469 MHz
Uw (see notes)	0.50	nm	Det.Jitter	4.28	ps inc. DCD	Connections C	1.50	dB	at 840 nm	c_rx 329 ns.MHz	
Tx pwr OMA=	0.00	dBm	DCD_DJ=	4.28	ps TP3	Pwr.Bud.-Conn.Loss	7.00	dB	Disp. min. Uo= 1316 nm	T_rx(10-90) 21.3 ps	Test Source ER=
Min. Ext Ratio=	6.43	dB	Effect. DJ=	0.00	(UI) ex DCD	C1=	480	ns.MHz	Disp. So= 0.10275 ps/nm^2*km	TP4 Eye 8 ps	*Test Tx* 6.5 dB
"Worst"ave.TxPwr	-1.0	dBm	MPN k(OMA)	0.3		Reflection Noise factor 0		no units	Disp. D1= -108.41 ps/(nm.km)	Opening (=Tx eye	TestERpen. 1.98 dBo
Ext. ratio penalty	2.01	dBo	Tx eye height	29.5%		Effective Rate	28977	MBd	γ = 1.0	RMS Baseline wander SD 0.013 fraction of 1/2 eye	
Tx mask X1=	0.3	UI	Refl Tx	-12	dB	Tb_eff=	35	ps	(not in use) 10	EFFBW	V.E.C.P. 6.24 dBo
X2=	0.4	UI	ModalNoisePen	0.3	dB	Effective Rec Eye	0.22	UI	BWm= 2000 MHz*km	P_BLW(no ISI) 0.02 dB	
Y1=	0.25		Tx mask top	0.2	UI				Eff. BWm= 2.0E+03 MHz*km	P_BLW 0.02 dB	

L (km)	Patt (dB)	Ch IL (dB)	D1.L ps/nm	D2.L ps/nm	BWcd (MHz)	effBWm (MHz)	Te (ps)	Tc (ps)	Pisi central J=0, dB	P Eye corners (dB)	P_DJ central (dB)	P_DJ corners (dB)	Preflection central (dB)	Beta	SDmpn	Pmpn (dB)	Prin (dB)	Pcross central (dB)	Ptotal central (dB)	<Ptotal corners (dB)	LP Pen central (dB)	10GbE Method Margin (dB)	Stressed Rx sens OMA central (dBm)
0.002	0.01	1.51	-0.22	0.00	2E+06	1.0E+06	36	42	3.86	0.29	0.00	0.00		0.00	0.00	0.00	1.00	-0.72	3.45	3.74	3.4	3.6	3.0
0.025	**0.09**	**1.59**	**-2.7**	**0.00**	**137,992**	**80,000**	**37**	**43**	**4.00**	**0.29**	**0.00**	**0.00**	**0**	**-0.04**	**0.00**	**0.00**	**1.00**	**0.40**	**5.8**	**6.1**	**5.7**	**1.2**	**2.4**
0.03	0.11	1.61	-3.3	0.00	114,994	66,667	37	43	4.06	0.29	0.00	0.00	0	-0.05	0.00	0.00	1.01	0.41	5.9	6.2	5.8	1.1	2.3
0.035	0.13	1.63	-3.8	0.00	98,566	57,143	38	43	4.13	0.29	0.00	0.00	0	-0.06	0.00	0.00	1.03	0.42	6.0	6.3	5.9	1.0	2.3
0.04	0.14	1.64	-4.3	0.00	86,245	50,000	38	44	4.22	0.30	0.00	0.00	0	-0.07	0.00	0.00	1.04	0.44	6.1	6.4	6.0	0.9	2.3
0.045	0.16	1.66	-4.9	0.00	76,662	44,444	39	44	4.31	0.30	0.00	0.00	0	-0.07	0.00	0.00	1.07	0.46	6.3	6.6	6.1	0.7	2.2
0.05	**0.18**	**1.68**	**-5.4**	**0.00**	**68,996**	**40,000**	**39**	**44**	**4.42**	**0.30**	**0.00**	**0.00**	**0**	**-0.08**	**0.00**	**0.00**	**1.10**	**0.49**	**6.5**	**6.8**	**6.31**	**0.5**	**2.2**
0.055	0.20	1.70	-6.0	0.00	62,724	36,364	39	45	4.54	0.30	0.00	0.00	0	-0.09	0.00	0.00	1.13	0.53	6.7	7.0	6.5	0.3	2.1
0.06	0.22	1.72	-6.5	0.00	57,497	33,333	40	45	4.67	0.30	0.00	0.00	0	-0.10	0.00	0.00	1.18	0.57	6.9	7.2	6.7	0.1	2.0
0.065	0.24	1.74	-7.0	0.00	53,074	30,769	41	46	4.82	0.31	0.00	0.00	0	-0.11	0.00	0.00	1.23	0.63	7.2	7.5	7.0	-0.2	1.9
0.07	0.25	1.75	-7.6	0.00	49,283	28,571	41	46	4.97	0.31	0.00	0.00	0	-0.11	0.00	0.00	1.30	0.70	7.5	7.8	7.3	-0.5	1.8
0.075	**0.27**	**1.77**	**-8.1**	**0.00**	**45,997**	**26,667**	**42**	**47**	**5.15**	**0.31**	**0.00**	**0.00**	**0**	**-0.12**	**0.00**	**0.00**	**1.39**	**0.80**	**7.9**	**8.2**	**7.6**	**-0.9**	**1.6**
0.08	0.29	1.79	-8.7	0.00	43,123	25,000	43	48	5.33	0.32	0.00	0.00	0	-0.13	0.00	0.00	1.50	0.93	8.4	8.7	8.1	-1.4	1.4
0.085	0.31	1.81	-9.2	0.00	40,586	23,529	43	48	5.53	0.33	0.00	0.00	0	-0.14	0.00	0.00	1.64	1.13	8.9	9.2	8.6	-1.9	1.2
0.09	0.33	1.83	-9.8	0.00	38,331	22,222	44	49	5.75	0.33	0.00	0.00	0	-0.15	0.00	0.00	1.82	1.43	9.6	10.0	9.3	-2.6	0.8
0.095	0.34	1.84	-10.3	0.00	36,314	21,053	45	50	5.98	0.34	0.00	0.00	0	-0.16	0.01	0.00	2.06	1.96	10.6	11.0	10.3	-3.6	0.3
0.10	**0.36**	**1.86**	**-10.8**	**0.00**	**34,498**	**20,000**	**46**	**50**	**6.24**	**0.35**	**0.00**	**0.00**	**0**	-0.16	0.01	**0.00**	**2.38**	**3.19**	**12.5**	**12.8**	**12.1**	**-5.5**	**-0.7**
0.105	0.38	1.88	-11.4	0.00	32,855	19,048	47	51	6.51	0.36	0.00	0.00	0	-0.17	0.01	0.00	2.86	#####	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!
0.11	0.40	1.90	-11.9	0.00	31,362	18,182	48	52	6.81	0.37	0.00	0.00	0	-0.18	0.01	0.00	3.65	#####	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!
0.115	0.42	1.92	-12.5	0.00	29,998	17,391	48	53	7.13	0.39	0.00	0.00	0	-0.19	0.01	0.01	5.36	#####	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!
0.125	0.45	1.95	-13.6	0.00	27,598	16,000	50	55	7.85	0.43	0.00	0.00	0	-0.20	0.01	0.01	#NUM!	#####	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!
0.15	**0.54**	**2.04**	**-16.3**	**0.01**	**22,999**	**13,333**	**55**	**59**	**10.50**	**0.66**	**0.00**	**0.00**	**0**	-0.25	**0.01**	**0.02**	**#NUM!**	**#####**	**#NUM!**	**#NUM!**	**#NUM!**	**#NUM!**	**#NUM!**

32GFC Std Spreadsheet at 25.78 GBd OM4 Fiber

Spreadsheet by David Cunningham, Avago Technologies

Basics	Input=	**Bold**	
	Q=	**7.04**	
	Base Rate=	**25781.3**	MBd
Transmitter			
	Wavelength Uc	**840**	nm
	Uw (see notes)	**0.50**	nm
	Tx pwr OMA=	**0.00**	dBm
	Min. Ext Ratio=	6.43	dB
	"Worst"ave.TxPwr	**-1.0**	dBm
	Ext. ratio penalty	2.01	dBo
Tx mask	X1=	**0.3**	UI
	X2=	**0.4**	UI
	Y1=	**0.25**	

Ts(20-80)	*24*	ps
Ts(10-90)	36	ps
RIN(OMA)	**-131**	dB/Hz
RIN at MinER	-135.0	dB/Hz
RIN_Coef=	**0.70**	
Det.Jitter	**4.28**	ps inc. DCD
DCD_DJ=	**4.28**	ps TP3
Effect. DJ=	0.00	(UI) ex DCD
MPN k(OMA)	**0.3**	
Tx eye height	29.6%	
Refl Tx	**-12**	dB
ModalNoisePen	**0.3**	dB
Tx mask top	0.2	UI

Case:	850nm serial	**newMMF**	
Target	Target reach	**0.10**	km
and	L_start=	**0.03**	km
graph	L_inc=	**0.01**	km
	Power Budget P=	8.50	dB
	Connections C	**1.50**	dB
	Pwr.Bud.-Conn.Loss	7.00	dB
	C1=	**480**	ns.MHz
	Reflection Noise factor	**0**	no units
	Effective Rate	28977	MBd
	Tb_eff=	35	ps
	Effective Rec Eye	0.22	UI

Rev.	#REF!	This file	
	Attenuation=	**3.5**	dB/km
Fiber	at	850	nm
	C_att=	1.00	
	Attenuation=	3.62	dB/km
	at	840	nm
	Disp. min. Uo=	**1316**	nm
	Disp. So=	**0.10275**	ps/nm^2*km
	Disp. D1=	-108.41	ps/(nm.km)
	γ =	**1.0**	
	(not in use)	**10**	
	BWm=	**4700**	MHz*km
	Eff. BWm=	4.7E+03	MHz*km

#REF!			
	Model/format rev	#REF!	
	NomSens OMA	**-8.50**	dBm
Receiver	Refl Rx	**-12**	dB
	Rec_BW=	**15,469**	MHz
	c_rx	**329**	ns.MHz
	T_rx(10-90)	21.3	ps
	TP4 Eye Opening	8	ps (=Tx eye
	RMS Baseline wander SD	**0.013**	fraction of 1/2 eye
STD			
	P_BLW(no ISI)	0.02	dB
	P_BLW	0.02	dB

of	#REF!		
of	#REF!		
Margin		-0.89	dB at
Answer!		0.1	km
Test Rx BW		**15,469**	MHz
Test Source ER=			
Test Tx		**6.5**	dB
TestERpen.		1.98	dBo
V.E.C.P.	4.73		dBo

L (km)	Patt (dB)	Ch IL (dB)	D1.L ps/nm	D2.L ps/nm	BWcd (MHz)	effBWm (MHz)	Te (ps)	Tc (ps)	Pisi central J=0, dB	P Eye corners (dB)	P_DJ central (dB)	P_DJ corners (dB)	Preflection central (dB)	Beta	SDmpn	Pmpn (dB)	Prin (dB)	Pcross central (dB)	Ptotal central (dB)	<Ptotal corners (dB)	LP Pen central (dB)	10GbE Method Margin (dB)	Stressed Rx sens OMA central (dBm)
0.002	0.01	1.51	-0.22	0.00	2E+06	2.4E+06	36	42	3.86	0.29	0.00	0.00		-0.01	0.00	0.00	0.99	-0.71	3.46	3.75	3.5	3.5	-1.6
0.025	**0.09**	**1.59**	**-2.7**	**0.00**	**137,992**	**188,000**	**37**	**42**	**3.91**	**0.29**	**0.00**	**0.00**	**0**	**-0.12**	**0.00**	**0.00**	**0.99**	**0.39**	**5.7**	**6.0**	**5.6**	**1.3**	**-2.2**
0.03	0.11	1.61	-3.3	0.00	114,994	156,667	37	43	3.94	0.29	0.00	0.00	0	-0.15	0.00	0.00	1.00	0.39	5.7	6.0	5.6	1.3	-2.2
0.035	0.13	1.63	-3.8	0.00	98,566	134,286	37	43	3.97	0.29	0.00	0.00	0	-0.17	0.01	0.00	1.00	0.40	5.8	6.1	5.7	1.2	-2.2
0.04	0.14	1.64	-4.3	0.00	86,245	117,500	37	43	4.00	0.29	0.00	0.00	0	-0.20	0.01	0.01	1.00	0.41	5.9	6.2	5.7	1.1	-2.3
0.045	0.16	1.66	-4.9	0.00	76,662	104,444	37	43	4.03	0.29	0.00	0.00	0	-0.22	0.01	0.01	1.01	0.42	5.9	6.2	5.8	1.1	-2.3
0.05	**0.18**	**1.68**	**-5.4**	**0.00**	**68,996**	**94,000**	**37**	**43**	**4.08**	**0.29**	**0.00**	**0.00**	**0**	**-0.25**	**0.01**	**0.02**	**1.02**	**0.43**	**6.0**	**6.3**	**5.84**	**1.0**	**-2.3**
0.055	0.20	1.70	-6.0	0.00	62,724	85,455	38	43	4.12	0.29	0.00	0.00	0	-0.27	0.02	0.02	1.02	0.45	6.1	6.4	5.9	0.9	-2.4
0.06	0.22	1.72	-6.5	0.00	57,497	78,333	38	43	4.17	0.29	0.00	0.00	0	-0.30	0.02	0.03	1.03	0.48	6.2	6.5	6.0	0.8	-2.4
0.065	0.24	1.74	-7.0	0.00	53,074	72,308	38	44	4.23	0.30	0.00	0.00	0	-0.32	0.02	0.05	1.05	0.50	6.4	6.7	6.1	0.6	-2.5
0.07	0.25	1.75	-7.6	0.00	49,283	67,143	38	44	4.28	0.30	0.00	0.00	0	-0.35	0.02	0.06	1.06	0.54	6.5	6.8	6.2	0.5	-2.6
0.075	**0.27**	**1.77**	**-8.1**	**0.00**	**45,997**	**62,667**	**39**	**44**	**4.35**	**0.30**	**0.00**	**0.00**	**0**	**-0.37**	**0.03**	**0.08**	**1.08**	**0.59**	**6.7**	**7.0**	**6.4**	**0.3**	**-2.6**
0.08	0.29	1.79	-8.7	0.00	43,123	58,750	39	44	4.42	0.30	0.00	0.00	0	-0.39	0.03	0.10	1.09	0.64	6.8	7.1	6.6	0.2	-2.7
0.085	0.31	1.81	-9.2	0.00	40,586	55,294	39	45	4.49	0.30	0.00	0.00	0	-0.42	0.03	0.13	1.12	0.71	7.1	7.4	6.7	-0.1	-2.8
0.09	0.33	1.83	-9.8	0.00	38,331	52,222	40	45	4.57	0.30	0.00	0.00	0	-0.44	0.04	0.16	1.14	0.80	7.3	7.6	7.0	-0.3	-2.9
0.095	0.34	1.84	-10.3	0.00	36,314	49,474	40	45	4.65	0.30	0.00	0.00	0	-0.47	0.04	0.20	1.17	0.91	7.6	7.9	7.2	-0.6	-3.1
0.10	**0.36**	**1.86**	**-10.8**	**0.00**	**34,498**	**47,000**	**40**	**46**	**4.73**	**0.31**	**0.00**	**0.00**	**0**	**-0.49**	**0.05**	**0.24**	**1.20**	**1.05**	**7.9**	**8.2**	**7.5**	**-0.9**	**-3.2**
0.105	0.38	1.88	-11.4	0.00	32,855	44,762	41	46	4.83	0.31	0.00	0.00	0	-0.52	0.05	0.29	1.24	1.24	8.3	8.6	7.9	-1.3	-3.4
0.11	0.40	1.90	-11.9	0.00	31,362	42,727	41	46	4.92	0.31	0.00	0.00	0	-0.54	0.05	0.34	1.28	1.49	8.7	9.0	8.3	-1.7	-3.7
0.115	0.42	1.92	-12.5	0.00	29,998	40,870	41	47	5.03	0.31	0.00	0.00	0	-0.57	0.06	0.40	1.33	1.85	9.3	9.6	8.9	-2.3	-4.0
0.12	0.43	1.93	-13.0	0.00	28,748	39,167	42	47	5.13	0.31	0.00	0.00	0	-0.59	0.06	0.47	1.39	2.38	10.1	10.4	9.7	-3.1	-4.4
0.15	**0.54**	**2.04**	**-16.3**	**0.01**	**22,999**	**31,333**	**45**	**49**	**5.90**	**0.34**	**0.00**	**0.00**	**0**	-0.74	**0.09**	**1.09**	**1.97**	**#####**	**#NUM!**	**#NUM!**	**#NUM!**	**#NUM!**	**#NUM!**

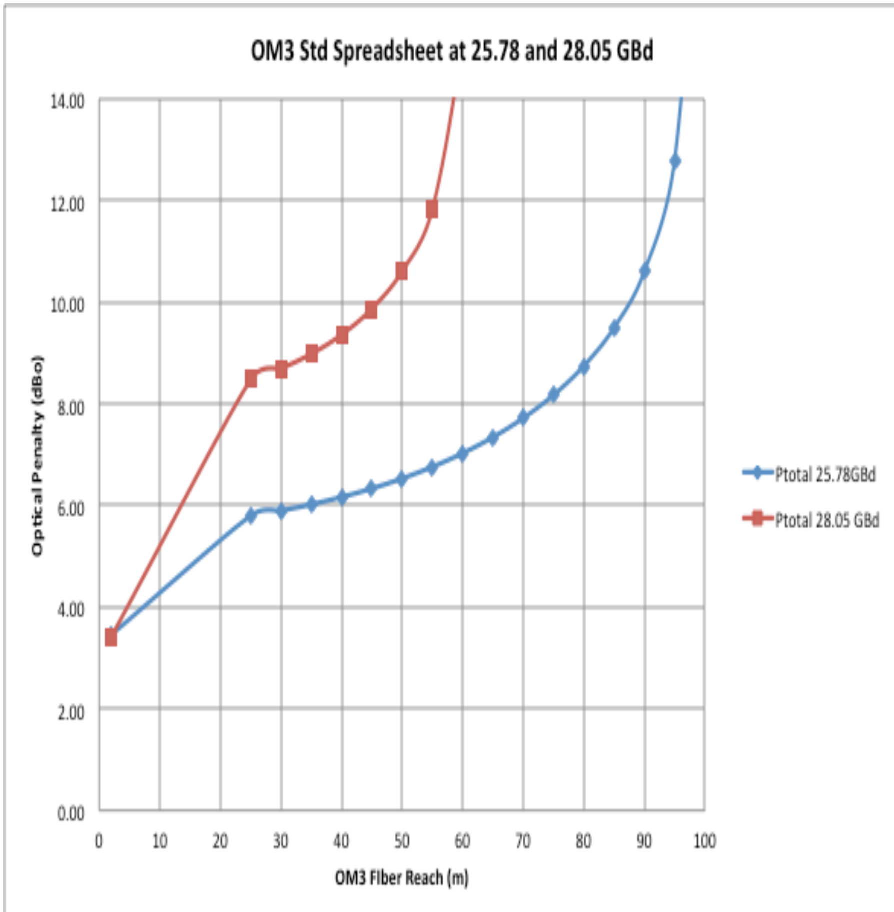
32GFC Spreadsheet at 25.78 GBd OM4 Fiber with EFF BW

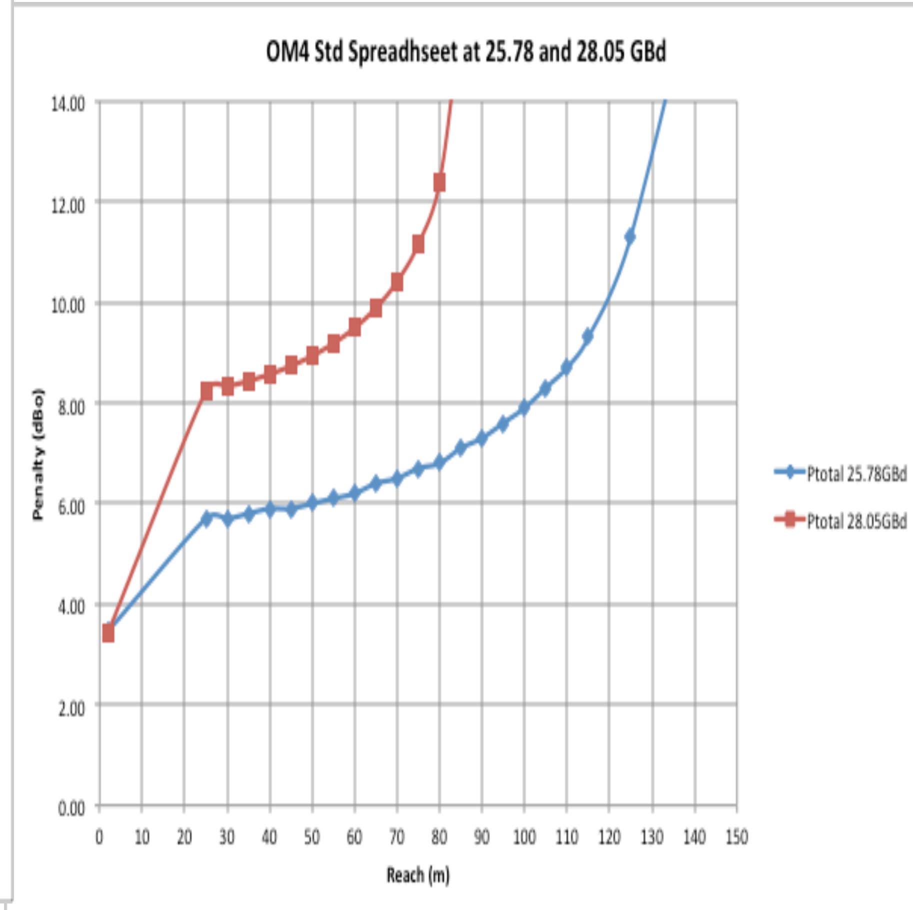
Spreadsheet by David Cunningham, Avago Technologies									Rev.	#REF!	This file	#REF!		of	#REF!
Basics	Input=	**Bold**	Ts(20-80)	24	ps	Case: 850nm serial		**newMMF**	Attenuation=	**3.5**	dB/km	Model/format rev	#REF!	of	#REF!
	Q=	**7.04**	Ts(10-90)	36	ps	*Target*	Target reach	**0.10** km	*Fiber* at	850	nm	NomSens OMA	**-8.50** dBm	Margin	-0.20 dB at
	Base Rate=	**25781.3** MBd	RIN(OMA)	**-131**	dB/Hz	*and*	L_start=	**0.03** km	C_att=	1.00		*Receiver* Refl Rx	**-12** dB	*Answer!*	0.1 km
Transmitter			RIN at MinER	-135.0	dB/Hz	*graph*	L_inc=	**0.01** km	Attenuation=	3.62	dB/km	Rec_BW=	**15,469** MHz	Test Rx BW	**15,469** MHz
	Wavelength Uc	**840** nm	RIN_Coef=	**0.70**			Power Budget P=	8.50 dB	at	840	nm	c_rx	**329** ns.MHz		
	Uw (see notes)	**0.50** nm	Det.Jitter	**4.28**	ps inc. DCD		Connections C	**1.50** dB	Disp. min. Uo=	**1316**	nm	T_rx(10-90)	21.3 ps	Test Source ER=	
	Tx pwr OMA=	**0.00** dBm	DCD_DJ=	**4.28**	ps TP3		Pwr.Bud.-Conn.Loss	7.00 dB	Disp. So=	**0.10275**	ps/nm^2*km	TP4 Eye	8 ps	*Test Tx*	**6.5** dB
	Min. Ext Ratio=	6.43 dB	Effect. DJ=	0.00	(UI) ex DCD		C1=	**480** ns.MHz	Disp. D1=	-108.41	ps/(nm.km)	Opening	(=Tx eye	TestERpen.	1.98 dBo
	"Worst"ave.TxPwr	**-1.0** dBm	MPN k(OMA)	**0.3**			Reflection Noise factor	**0** no units	γ =	**1.0**	RMS Baseline wander SD		**0.013** fraction of 1/2 eye		
	Ext. ratio penalty	2.01 dBo	Tx eye height	29.6%			Effective Rate	28977 MBd	(not in use)	**10**		EFFBW		V.E.C.P.	4.73 dBo
Tx mask	X1=	**0.3** UI	Refl Tx	**-12**	dB		Tb_eff=	35 ps	BWm=	**4700**	MHz*km	P_BLW(no ISI)	0.02 dB		
	X2=	**0.4** UI	ModalNoisePen	**0.3**	dB		Effective Rec Eye	0.22 UI	Eff. BWm=	4.7E+03	MHz*km	P_BLW	0.02 dB		
	Y1=	**0.25**	Tx mask top	0.2	UI										

L (km)	Patt (dB)	Ch IL (dB)	D1.L ps/nm	D2.L ps/nm	BWcd (MHz)	effBWm (MHz)	Te (ps)	Tc (ps)	Pisi central J=0, dB	P Eye corners (dB)	P_DJ central (dB)	P_DJ corners (dB)	Preflection central (dB)	Beta	SDmpn	Pmpn (dB)	Prin (dB)	Pcross central (dB)	Ptotal central (dB)	<Ptotal corners (dB)	LP Pen central (dB)	10GbE Method Margin (dB)	Stressed Rx sens OMA central (dBm)
0.002	0.01	1.51	-0.22	0.00	2E+06	2.4E+06	36	42	3.86	0.29	0.00	0.00		0.00	0.00	0.00	0.99	-0.71	3.46	3.75	3.5	3.5	-2.2
0.025	**0.09**	**1.59**	**-2.7**	**0.00**	**137,992**	**188,000**	**37**	**42**	**3.91**	**0.29**	**0.00**	**0.00**	**0**	**-0.04**	**0.00**	**0.00**	**0.99**	**0.39**	**5.7**	**6.0**	**5.6**	**1.3**	**-2.9**
0.03	0.11	1.61	-3.3	0.00	114,994	156,667	37	43	3.94	0.29	0.00	0.00	0	-0.05	0.00	0.00	1.00	0.39	5.7	6.0	5.6	1.3	-2.9
0.035	0.13	1.63	-3.8	0.00	98,566	134,286	37	43	3.97	0.29	0.00	0.00	0	-0.06	0.00	0.00	1.00	0.39	5.8	6.1	5.7	1.2	-2.9
0.04	0.14	1.64	-4.3	0.00	86,245	117,500	37	43	4.00	0.29	0.00	0.00	0	-0.07	0.00	0.00	1.00	0.40	5.8	6.1	5.7	1.2	-2.9
0.045	0.16	1.66	-4.9	0.00	76,662	104,444	37	43	4.03	0.29	0.00	0.00	0	-0.07	0.00	0.00	1.01	0.41	5.9	6.2	5.7	1.1	-3.0
0.05	**0.18**	**1.68**	**-5.4**	**0.00**	**68,996**	**94,000**	**37**	**43**	**4.08**	**0.29**	**0.00**	**0.00**	**0**	**-0.08**	**0.00**	**0.00**	**1.02**	**0.41**	**6.0**	**6.3**	**5.80**	**1.0**	**-3.0**
0.055	0.20	1.70	-6.0	0.00	62,724	85,455	38	43	4.12	0.29	0.00	0.00	0	-0.09	0.00	0.00	1.02	0.42	6.1	6.4	5.9	0.9	-3.0
0.06	0.22	1.72	-6.5	0.00	57,497	78,333	38	43	4.17	0.29	0.00	0.00	0	-0.10	0.00	0.00	1.03	0.43	6.2	6.4	5.9	0.8	-3.1
0.065	0.24	1.74	-7.0	0.00	53,074	72,308	38	44	4.23	0.30	0.00	0.00	0	-0.11	0.00	0.00	1.05	0.44	6.3	6.5	6.0	0.7	-3.1
0.07	0.25	1.75	-7.6	0.00	49,283	67,143	38	44	4.28	0.30	0.00	0.00	0	-0.11	0.00	0.00	1.06	0.46	6.4	6.7	6.1	0.6	-3.1
0.075	**0.27**	**1.77**	**-8.1**	**0.00**	**45,997**	**62,667**	**39**	**44**	**4.35**	**0.30**	**0.00**	**0.00**	**0**	**-0.12**	**0.00**	**0.00**	**1.08**	**0.47**	**6.5**	**6.8**	**6.2**	**0.5**	**-3.2**
0.08	0.29	1.79	-8.7	0.00	43,123	58,750	39	44	4.42	0.30	0.00	0.00	0	-0.13	0.00	0.00	1.09	0.49	6.6	6.9	6.3	0.4	-3.2
0.085	0.31	1.81	-9.2	0.00	40,586	55,294	39	45	4.49	0.30	0.00	0.00	0	-0.14	0.00	0.00	1.12	0.51	6.7	7.0	6.4	0.3	-3.3
0.09	0.33	1.83	-9.8	0.00	38,331	52,222	40	45	4.57	0.30	0.00	0.00	0	-0.15	0.00	0.00	1.14	0.54	6.9	7.2	6.5	0.1	-3.3
0.095	0.34	1.84	-10.3	0.00	36,314	49,474	40	45	4.65	0.30	0.00	0.00	0	-0.16	0.01	0.00	1.17	0.56	7.0	7.3	6.7	0.0	-3.4
0.10	**0.36**	**1.86**	**-10.8**	**0.00**	**34,498**	**47,000**	**40**	**46**	**4.73**	**0.31**	**0.00**	**0.00**	**0**	**-0.16**	**0.01**	**0.00**	**1.20**	**0.60**	**7.2**	**7.5**	**6.8**	**-0.2**	**-3.5**
0.105	0.38	1.88	-11.4	0.00	32,855	44,762	41	46	4.83	0.31	0.00	0.00	0	-0.17	0.01	0.00	1.24	0.64	7.4	7.7	7.0	-0.4	-3.5
0.11	0.40	1.90	-11.9	0.00	31,362	42,727	41	46	4.92	0.31	0.00	0.00	0	-0.18	0.01	0.00	1.28	0.68	7.6	7.9	7.2	-0.6	-3.6
0.115	0.42	1.92	-12.5	0.00	29,998	40,870	41	47	5.03	0.31	0.00	0.00	0	-0.19	0.01	0.01	1.33	0.74	7.8	8.1	7.4	-0.8	-3.7
0.12	0.43	1.93	-13.0	0.00	28,748	39,167	42	47	5.13	0.31	0.00	0.00	0	-0.20	0.01	0.01	1.39	0.80	8.1	8.4	7.6	-1.1	-3.8
0.15	**0.54**	**2.04**	**-16.3**	**0.01**	**22,999**	**31,333**	**45**	**49**	**5.90**	**0.34**	**0.00**	**0.00**	**0**	**-0.25**	**0.01**	**0.02**	**1.97**	**1.82**	**10.5**	**10.9**	**10.0**	**-3.5**	**-5.0**

Operating at 25.78 vs 28.05 GBd

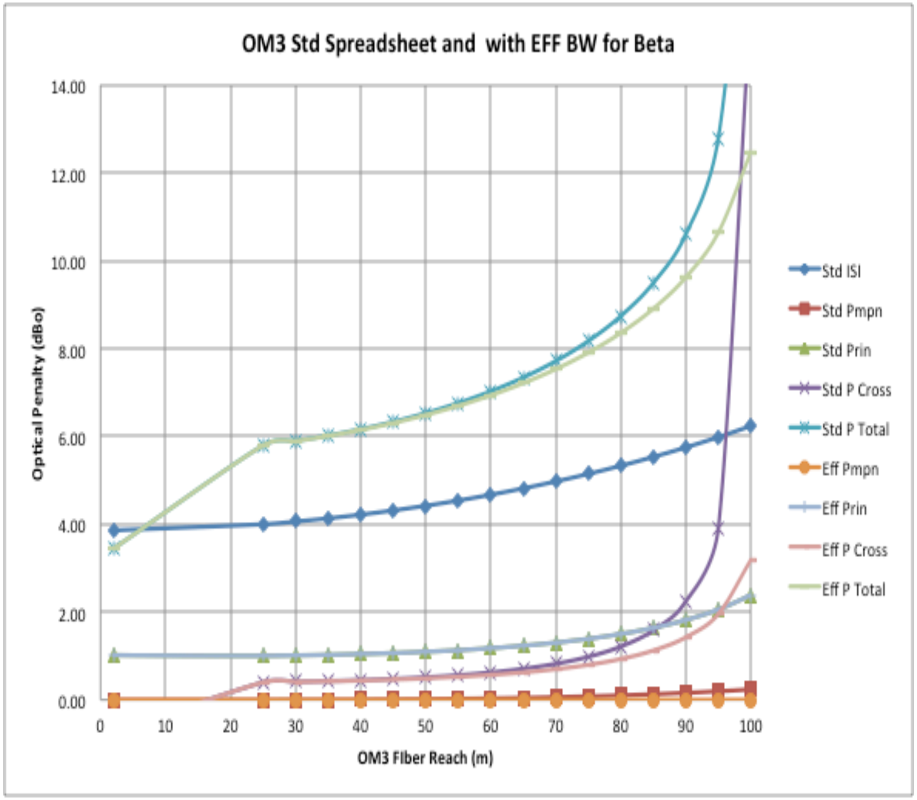
- 100G-SR4 if operates with overhead FEC the link penalty would be larger than the FEC gain
  - Zero overhead FEC does have the undesirable higher latency!

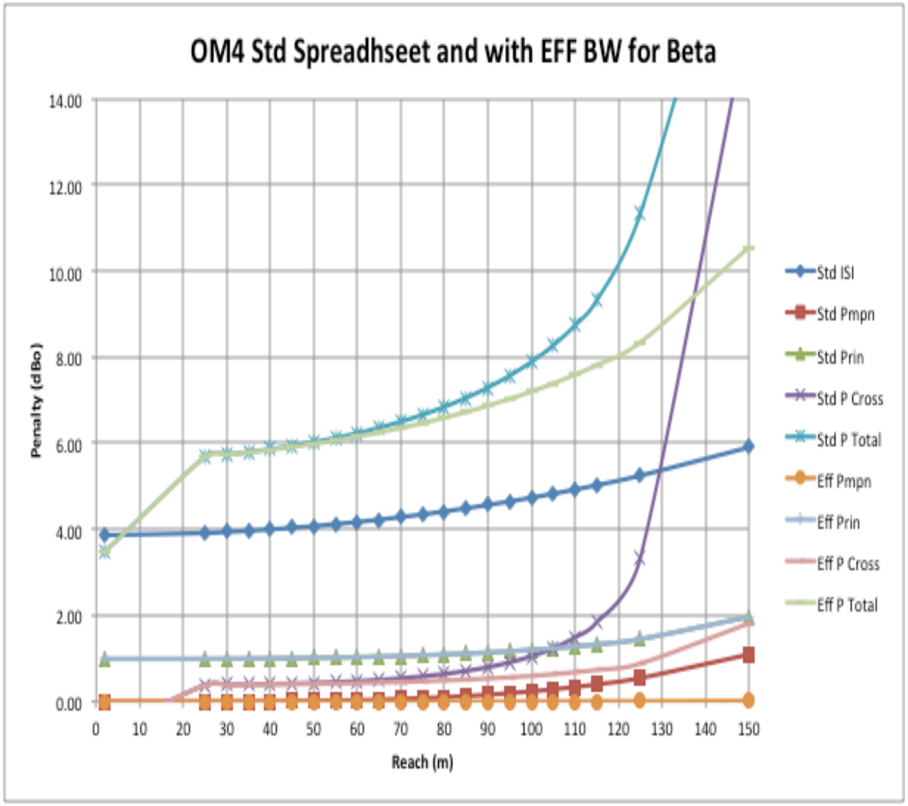




Spreadsheet Penalty Comparisons

- Using current method to calculate BW B in beta calculation as well as using EFF BW based on the laser rise time





Summary

- Investigated 25.78 GBd VCSEL link based on rate equation
  - For actual measurement see ghiasi_01_0312
- VCSEL inherent penalty is ~4 dBo of optical penalty at B2B where at 10G typical VCSEL B2B penalty was ~1.5 dBo
- MPN noise and cross penalty grows exponentially and more investigation is need to see if current assumption are correct
  - Such Gaussian model
  - Use of 1/(T-DCD) for BW
  - When the noise penalty start increasing very little reach can be gained by use of FEC or equalizer
  - Use of FEC with overhead is not an option as FEC gain will be less than the penalty increase due to MPN can and cross term as result of operating faster
- Benefit of equalized link
  - Address band limitations associated with VCSEL and photo detector
  - At 25.78GBd 100 m on OM3 or 150 m on OM4 could be supported and less at 28.05 GBd
  - Could get to 150 m OM4 each with combination of EFF BW and EQ or about 90 m on OM3

Thank You