Link Model Simulation and Power Penalty Specification of the Versatile Link System

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Southern Methodist University

The Question

"I was told that power should be measured in dBm"

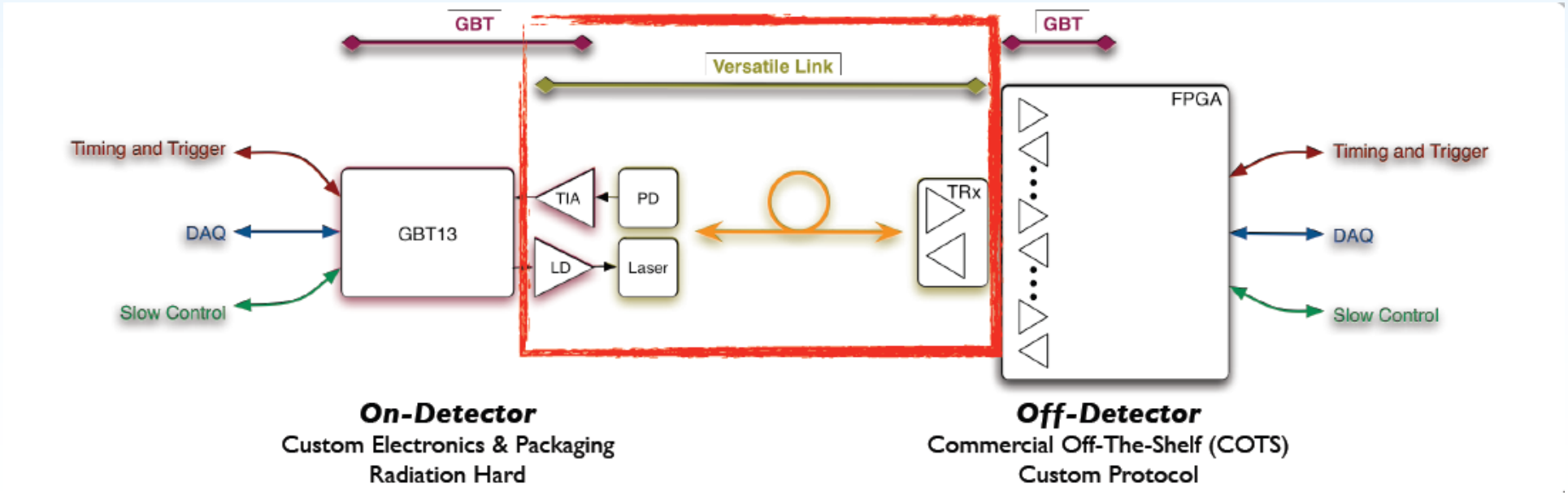
"The deficit won't look nearly so bad if we switch to dB"

Outline

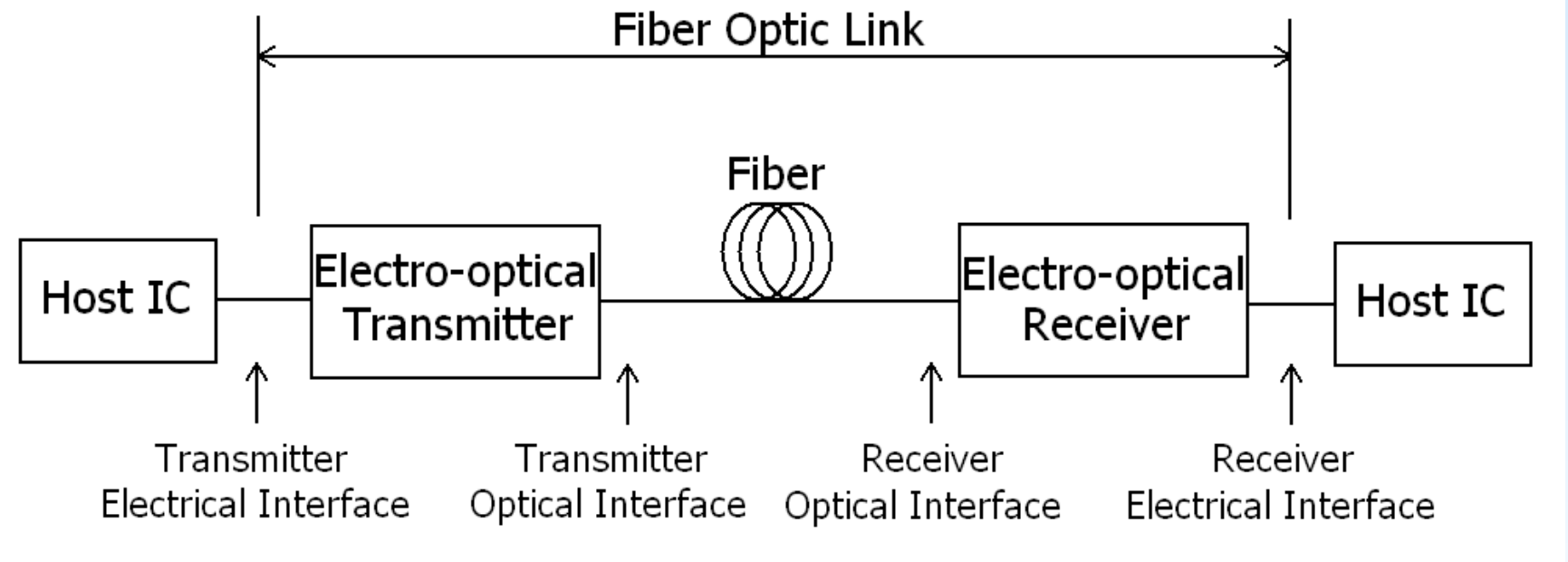
- Introduction
- Versatile Link specification methodology
- 10 Gigabit Ethernet link model
- Link model simulation with Versatile Link parameters
- BER results of reference transceivers
- Irradiation effects of link components
- Versatile Link preliminary power budget
- Summary

Introduction

- Versatile link project provides ~ 5Gbps, 150 meters bidirectional optical links at physical layer using lasers, PIN diodes and fibers.
  - In collaboration with the GBT project, which provides serial interface as well as ASICs for front-end component.
- Versatile link project accommodates various configurations: multimode (850nm), single mode (1310nm), point-to-point and point-to-multipoint.
  - Nominal form factor is SFP+. Expansion to other form factors require only marginal efforts.

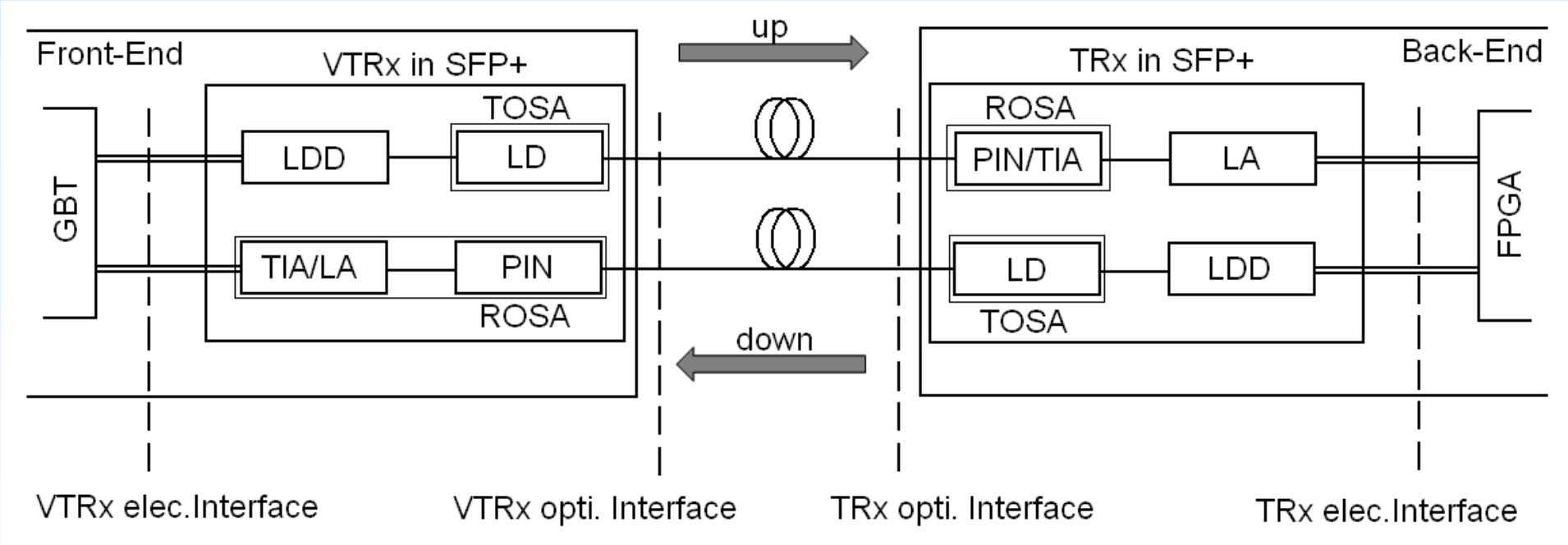


General Optic Link System Definition



- Fiber optic links are typically divided into functional blocks and interfaces similar to the one shown above.
- System specifications apportion power and jitter budget along link components to ensure BER < 1E-12 performance at target data rate, link length, across operating temperature range and throughout life cycle.

Versatile Link System Definition



- In the Versatile Link system, the VTRx resides on-detector and is custom designed. Fiber and back-end TRx will be commercially sourced.
- There are four configurations that need to be specified individually.
  - MM_VTx_Rx, MM_Tx_VRx, SM_VTx_Rx, SM_Tx_VRx

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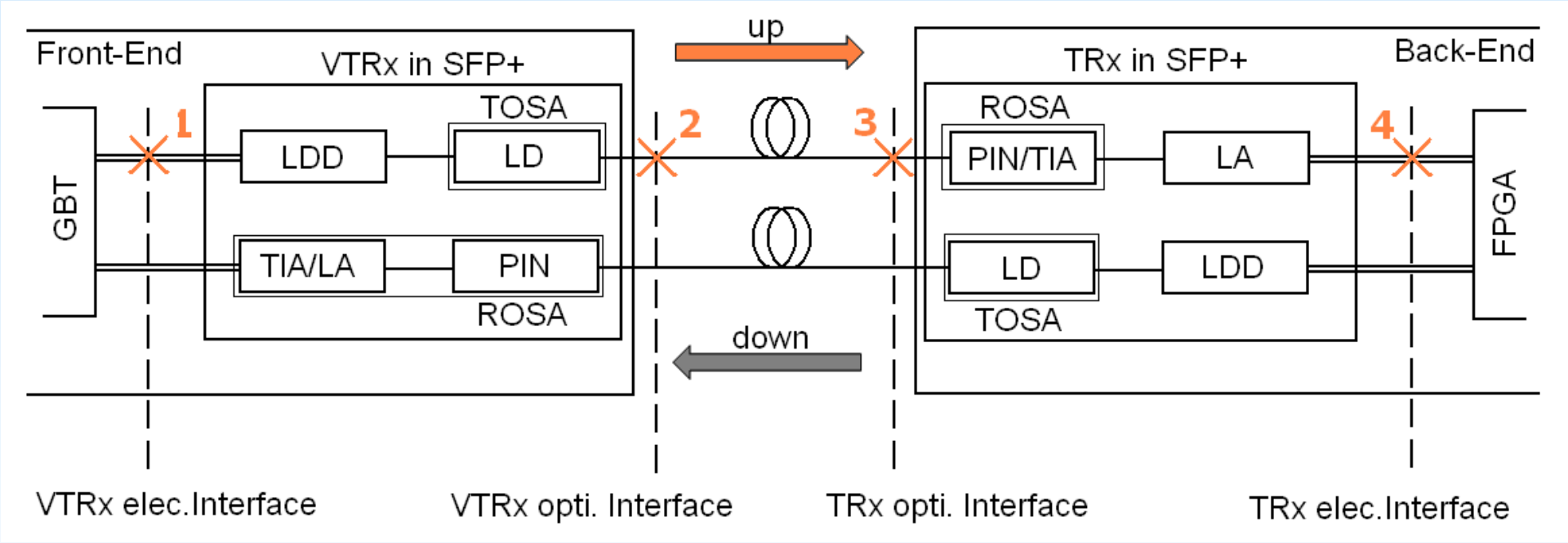

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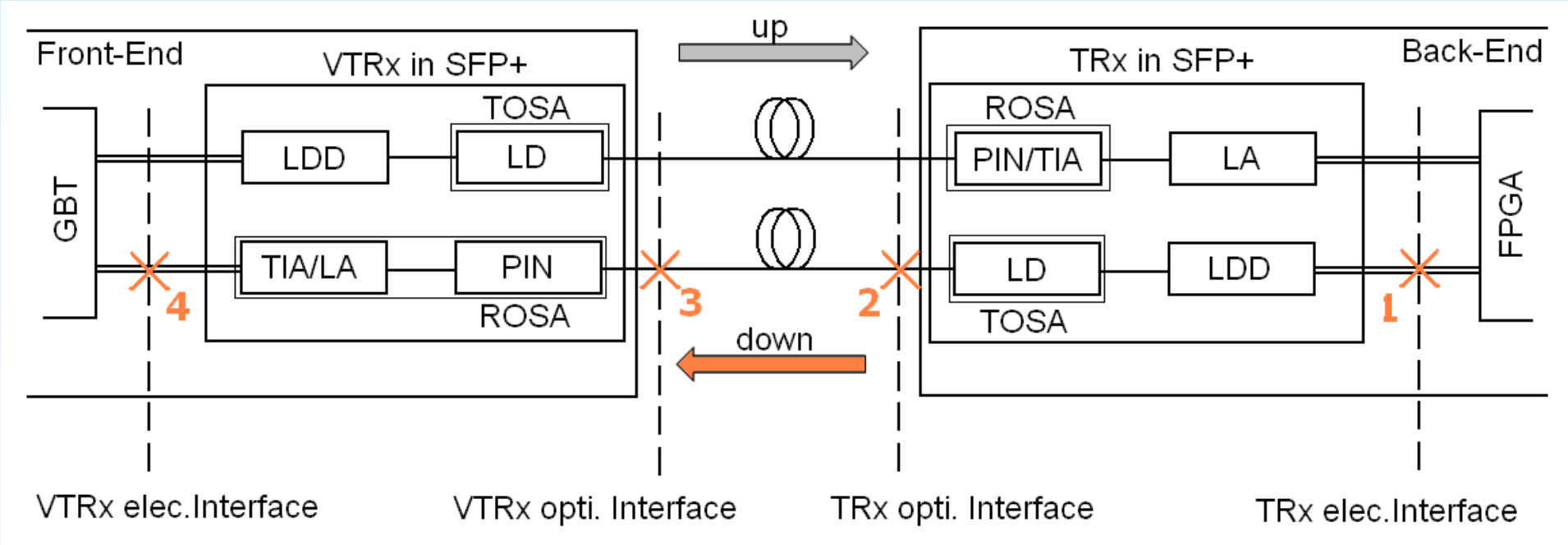

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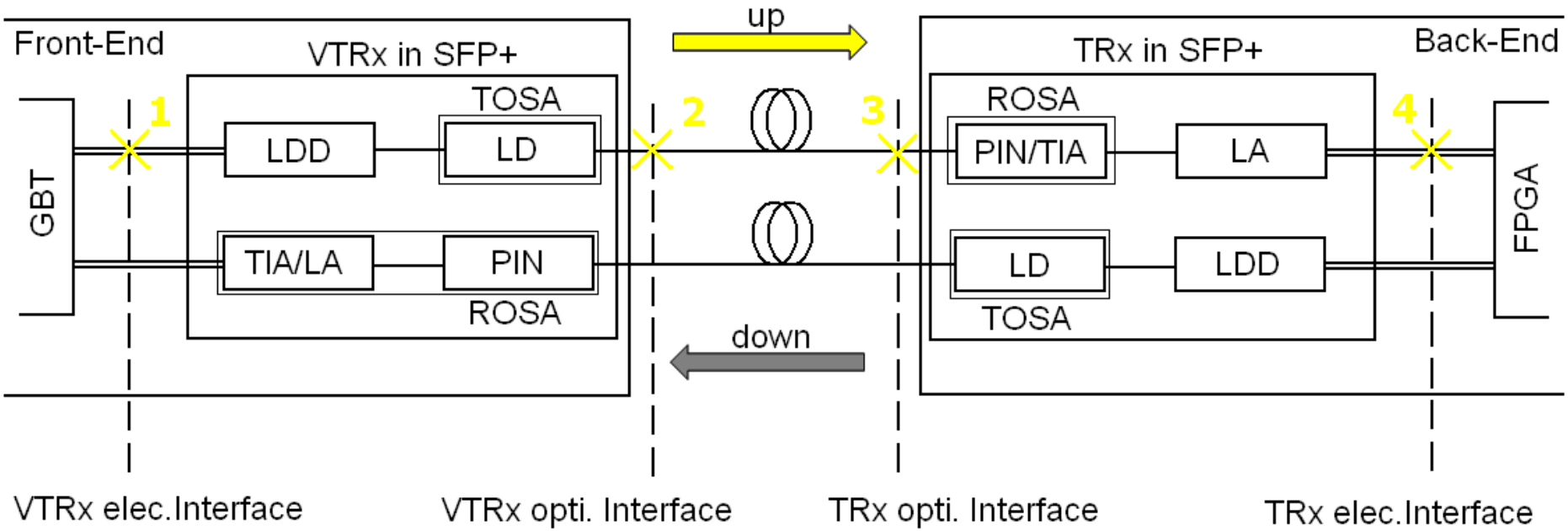

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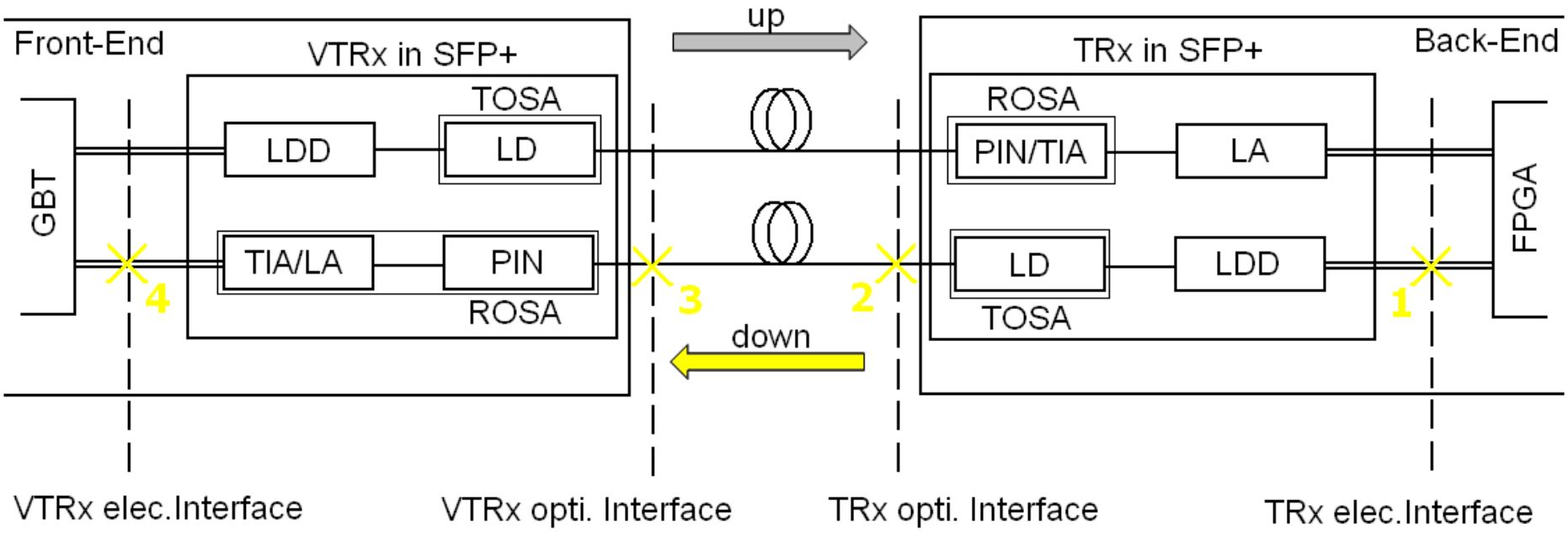

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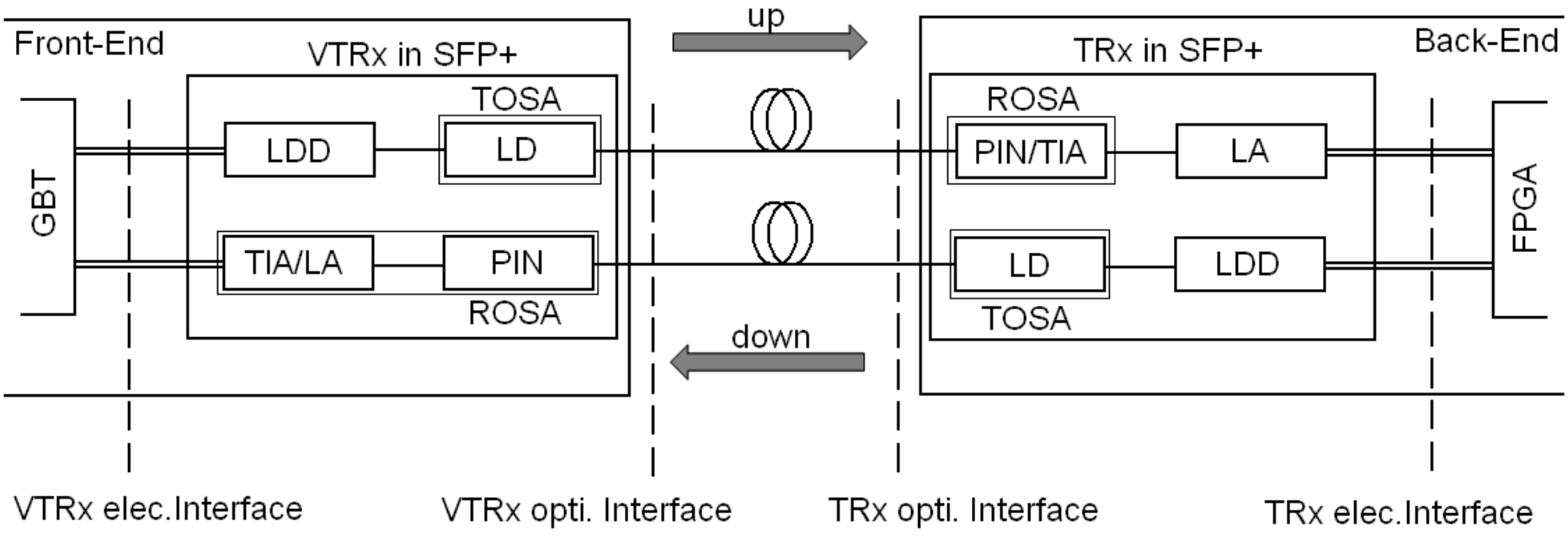
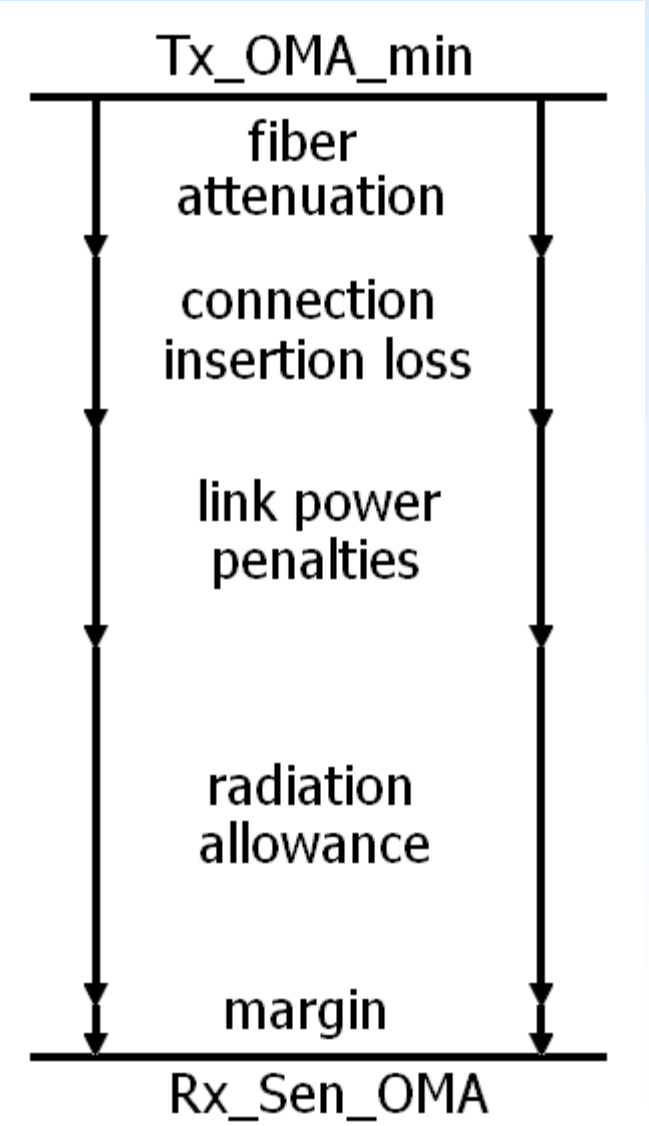
Versatile Link Specification Methodology



- At system level, power and jitter need to be budgeted for every specific link configuration.
  - Constrain: front-end components are known to exhibit power degradation due to radiation.
  - Solution: test front-end components, simulate link impairments and qualify back-end components.
  - Goal: budget overall link power based on availability and cost efficiency.

Power Budget Definition

- Defining a link power budget involves deciding transmit power, receiver sensitivity with constrains on fiber attenuations, insertion losses, and various penalties.
- VL needs to assign radiation allowance.
- Several tradeoffs are possible
  - Link penalties are related to parameters such as center wavelength, spectral width, rise/fall time etc.
  - Improvement of Tx power or Rx sensitivity can be achieved.
  - Higher level system requirement may be relaxed.



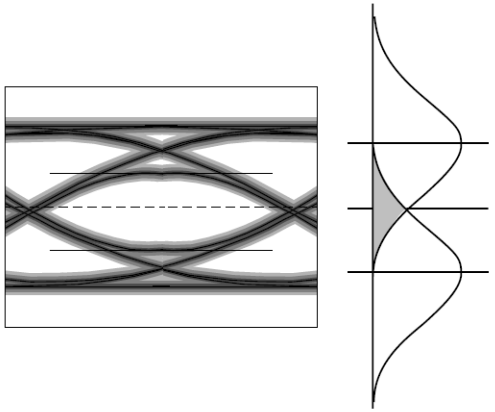
Power Budget Example

- Example budgets for
  - 300m OM3 (2000MHz.km)
  - 10km SMF28 (1E6MHz.km)
- Fiber attenuation
  - 3.5 dB/km at 850nm
  - 0.4 dB/km at 1310nm
- Insertions loss
  - 1.5 dB for up to 3 connectors at 850nm
  - 2.0 dB for up to 4 connectors at 1310 nm
- Un-distorted transmitter and un-equalized receiver
- Link penalties arise due to noise and dispersion from transceiver and fiber interactions.

	10GBASE-S	10GBASE-R
Tx_OMA (dBm)	-3.8	-3.2
S_OMA (dBm)	-11.1	-12.6
Power Budget (dB)	7.3	9.4
Attn.	1.1	4.2
Insert.	1.5	2.0
Allocation for Penalties	4.7	3.2
margin	0.0	0.0

10Gigabit Ethernet Link Model

- A 10 Gigabit Ethernet link model has been developed by IEEE as a tool to facilitate optical physical layer specification.
  - It is open source, peer reviewed
  - The latest version (10GEPBud3_1_16a.xls) is available at http://www.ieee802.org/3/ae/public/adhoc/serial_pmd/documents/
- The model assumes Gaussian impulse responses for laser and fiber, and raised cosine response for the receiver.
- The model simulates link impairments as noise expansion and vertical eye closure, and calculates power penalties at a target BER of 1E-12.
- Link impairments phenomena included: inter-symbol-interference (ISI), mode partition noise (MPN), modal noise (MN), relative intensity noise (RIN), reflection, duty-cycle-distortion (DCD) and interaction correction.



$$P_{isi} = 10 \cdot \log \frac{1}{2 \cdot h(0) - 1}$$

$$ht = \frac{1}{2} \cdot erf\left(\frac{2.563}{2 \cdot \sqrt{2}}\right) \cdot \frac{(2 \cdot t + T_{eff})}{T_c} - erf\left(\frac{2.563}{2 \cdot \sqrt{2}}\right) \cdot \left(\frac{2 \cdot t - T_{eff}}{T_c}\right)$$

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

$$\sigma_{mpn} = \frac{k_{OMA}}{\sqrt{2}} \cdot \{1 - \exp[-(\pi \cdot B_{eff} \cdot D \cdot L \cdot \sigma_\lambda)^2]\}$$

10Gigabit Ethernet Link Model

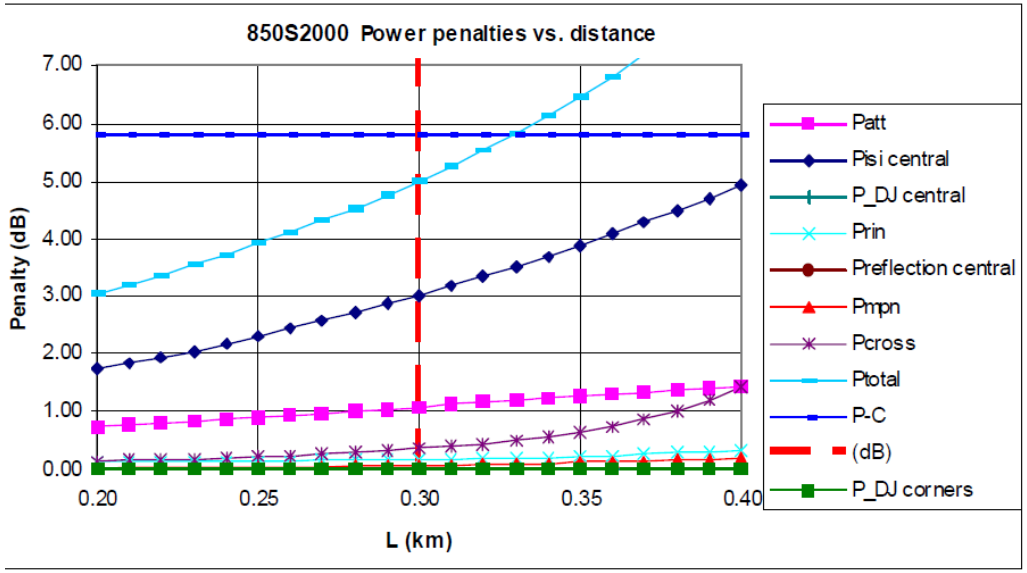
Versatile Link

- The model is build in excel spreadsheet. The outputs are the various penalties as functions of link length.
  - Channel is nonlinear with regard to data rate and length.
- The model has been validated by experiments in multiple labs
  - G. Agrawal et al,1988

Spreadsheet by Del Hanson, David Cunningham, Piers Dawe, David Dolfi Agilent Technologies — Rev. 3.2/3 — This file 10GEPBud3_1_16a.xls of 17-Oct-01

Basics	Input=	Bold			Ts(20-80)	76	ps	Case: 1310nm serial	SMF	Attenuation=	0.4	dB/km	Model/format rev	3.1 16a	of	31-Oct-01
	Q=	7.04			Ts(10-90)	115	ps	*Target* Target reach	0.15	km	*Fiber* at	1310	nm	NomSens OMA	-12.59	dBm	Margin	5.91	dB at
	Base Rate=	5000	MBd		RIN(OMA)	-130	dB/Hz	*and* L_start=	0.01	km	C_att=	0.27		*Receive* Refl Rx	-12	dB	*Answer!*	0.15	km
Transmitter					RIN at MinER	-137.3	dB/Hz	*graph* L_inc=	0.01	km	Attenuation=	0.42	dB/km	Rec_BW=	7,725	MHz	est Rx BW	7500	MHz
Wavelength	Uc	1260	nm		RIN_Coef=	0.70		Power Budget P=	9.39	dB	at	1260	nm	c_rx	329	ns.MHz			
Uw (see notes)		0.20	nm		Det.Jitter	6.0	ps inc. DCD	Connections C	2	dB	Disp. min. Uo=	1324	nm	T_rx(10-90)	42.6	ps	Test Source ER=		
Tx pwr OMA=		-3.20	dBm		DCD_DJ=	6	ps TP3	Pwr.Bud.-Conn.Loss	7.39	dB	Disp. So=	0.093	ps/nm^2*km	TP4 Eye	40	ps	*Test Tx*	6	dB
Min. Ext Ratio=		4.00	dB		Effect. DJ=	0.00	(UI) ex DCD	C1=	480	ns.MHz	Disp. D1=	-6.42	ps/(nm.km)	Opening		(=Tx eye	TestERpe	2.23	dBo
"Worst"ave.TxPwr		-2.55	dBm		MPN k(OMA)	0		Reflection Noise factor	0.6	no units				RMS Baseline wander SD	0.025	fraction of 1/2 eye			
Ext. ratio penalty		3.66	dBo		Tx eye height	80.6%		Effective Rate	5155	MBd	PolMD DGDmax	10	ps at target	0.15km			V.E.C.P.	0.35	dBo
Tx mask	X1=	0.3	UI		Refl Tx	-12	dB	Tb_eff=	194	ps	BWm=	1E+06	MHz*km	P_BLW(no ISI)	0.07	dB			Stressed
	X2=	0.4	UI		ModalNoisePen	0	dB	Effective Rec Eye	0.21	UI	Eff. BWm=	######	MHz*km	P_BLW	0.07	dB			Rx sens
	Y1=	0.25			Tx mask top	0.2	UI												

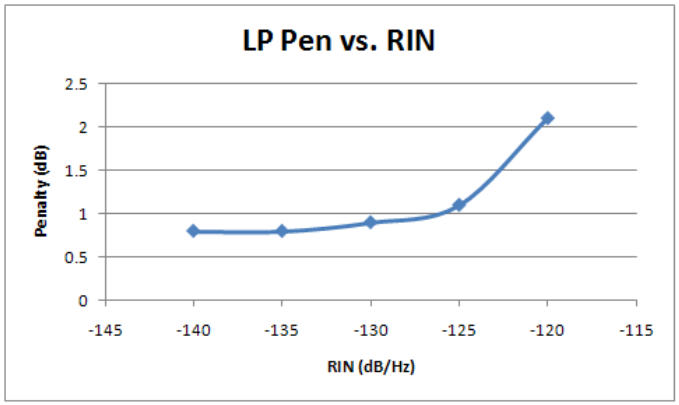
L	Patt	Ch IL	D1.L	D2.L	BWcd	effBWm	Te	Tc	Pisi central	Pisi corners	P Eye central	P Eye corners	P_DJ central	P_DJ corners	Preflection central	Beta	SDmpn	Pmpn	Prin	Pcross central	Ptotal central	Ptotal <corners	LP Pen central	LP Pen Margin	OMA central
(km)	(dB)	(dB)	ps/nm	ps/nm	(MHz)	(MHz)	(ps)	(ps)	J=0, dB	(dB)	(dB)	(dB)	(dB)	(dB)	(dB)			(dB)	(dB)	(dB)	(dB)	(dB)	(dB)	(dB)	(dBm)
0.002	0.00	2.00	-0.01	0.00	7E+07	######	115	123	0.39	0.18	0.00	0.00				-4E-05	0.00	0.00		0.02	0.41	0.59	0.4	7.0	-11.1
0.01	**0.00**	**2.00**	**-0.1**	**0.00**	**14,561,481**	**500,000**	**115**	**123**	**0.39**	**0.18**	**0.00**	**0.00**	**0.82**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.15**	**0.06**	**1.4**	**1.6**	**1.4**	**6.0**	**-12.1**
0.02	0.01	2.01	-0.1	0.00	7,280,741	250,000	115	123	0.39	0.18	0.00	0.00	0.82	0.00	0.00	0.00	0.00	0.00	0.15	0.06	1.4	1.6	1.4	6.0	-12.1
0.03	0.01	2.01	-0.2	0.00	4,853,827	166,667	115	123	0.39	0.18	0.00	0.00	0.81	0.00	0.00	0.00	0.00	0.00	0.15	0.06	1.4	1.6	1.4	6.0	-12.1
0.04	0.02	2.02	-0.3	0.00	3,640,370	125,000	115	123	0.39	0.18	0.00	0.00	0.81	0.00	0.00	0.00	0.00	0.00	0.15	0.06	1.4	1.6	1.4	6.0	-12.1
0.05	0.02	2.02	-0.3	0.00	2,912,296	100,000	115	123	0.39	0.18	0.00	0.00	0.81	0.00	0.00	0.00	0.00	0.00	0.15	0.06	1.4	1.6	1.4	5.9	-12.1
0.06	**0.03**	**2.03**	**-0.4**	**0.00**	**2,426,914**	**83,333**	**116**	**123**	**0.39**	**0.18**	**0.00**	**0.00**	**0.81**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.15**	**0.06**	**1.4**	**1.6**	**1.4**	**5.9**	**-12.1**
0.07	0.03	2.03	-0.4	0.00	2,080,212	71,429	116	123	0.40	0.18	0.00	0.00	0.81	0.00	0.00	0.00	0.00	0.00	0.15	0.06	1.4	1.6	1.4	5.9	-12.1
0.08	0.03	2.03	-0.5	0.00	1,820,185	62,500	116	123	0.40	0.18	0.00	0.00	0.81	0.00	0.00	0.00	0.00	0.00	0.15	0.06	1.5	1.6	1.4	5.9	-12.1
0.09	0.04	2.04	-0.6	0.00	1,617,942	55,556	116	123	0.40	0.18	0.00	0.00	0.81	0.00	0.00	0.00	0.00	0.00	0.15	0.06	1.5	1.6	1.4	5.9	-12.1
0.10	0.04	2.04	-0.6	0.00	1,456,148	50,000	116	123	0.40	0.18	0.00	0.00	0.81	0.00	0.00	0.00	0.00	0.00	0.15	0.06	1.5	1.6	1.4	5.9	-12.1
0.11	**0.05**	**2.05**	**-0.7**	**0.00**	**1,323,771**	**45,455**	**116**	**123**	**0.40**	**0.18**	**0.00**	**0.00**	**0.81**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.15**	**0.06**	**1.5**	**1.6**	**1.4**	**5.9**	**-12.1**
0.12	0.05	2.05	-0.8	0.00	1,213,457	41,667	116	124	0.40	0.18	0.00	0.00	0.81	0.00	0.00	0.00	0.00	0.00	0.15	0.06	1.5	1.6	1.4	5.9	-12.1
0.13	0.05	2.05	-0.8	0.00	1,120,114	38,462	116	124	0.40	0.18	0.00	0.00	0.81	0.00	0.00	0.00	0.00	0.00	0.15	0.06	1.5	1.7	1.4	5.9	-12.1
0.14	0.06	2.06	-0.9	0.00	1,040,106	35,714	116	124	0.40	0.18	0.00	0.00	0.81	0.00	0.00	0.00	0.00	0.00	0.15	0.06	1.5	1.7	1.4	5.9	-12.2
0.15	0.06	2.06	-1.0	0.00	970,765	33,333	116	124	0.41	0.18	0.00	0.00	0.81	0.00	0.00	0.00	0.00	0.00	0.14	0.06	1.5	1.7	1.4	5.9	-12.2
0.16	**0.07**	**2.07**	**-1.0**	**0.00**	**910,093**	**31,250**	**116**	**124**	**0.41**	**0.18**	**0.00**	**0.00**	**0.81**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.14**	**0.06**	**1.5**	**1.7**	**1.4**	**5.9**	**-12.2**
0.17	0.07	2.07	-1.1	0.00	856,558	29,412	117	124	0.41	0.18	0.00	0.00	0.81	0.00	0.00	0.00	0.00	0.00	0.14	0.06	1.5	1.7	1.4	5.9	-12.2
0.18	0.08	2.08	-1.2	0.00	808,971	27,778	117	124	0.41	0.18	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.14	0.06	1.5	1.7	1.4	5.9	-12.2
0.19	0.08	2.08	-1.2	0.00	766,394	26,316	117	124	0.41	0.18	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.14	0.06	1.5	1.7	1.4	5.9	-12.2
0.20	0.08	2.08	-1.3	0.00	728,074	25,000	117	124	0.42	0.18	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.14	0.06	1.5	1.7	1.4	5.9	-12.2
0.21	**0.09**	**2.09**	**-1.3**	**0.00**	**693,404**	**23,810**	**117**	**125**	**0.42**	**0.18**	**0.00**	**0.00**	**0.80**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.14**	**0.06**	**1.5**	**1.7**	**1.4**	**5.9**	**-12.2**

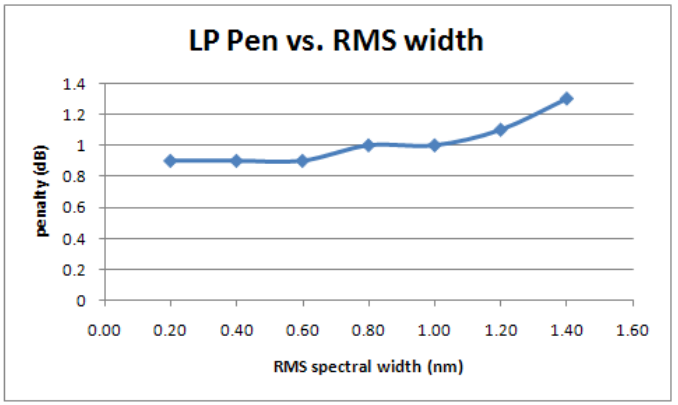


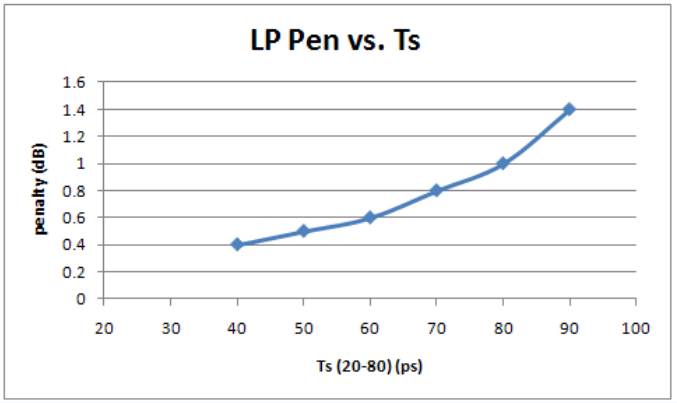
Versatile Link Model Key Parameters

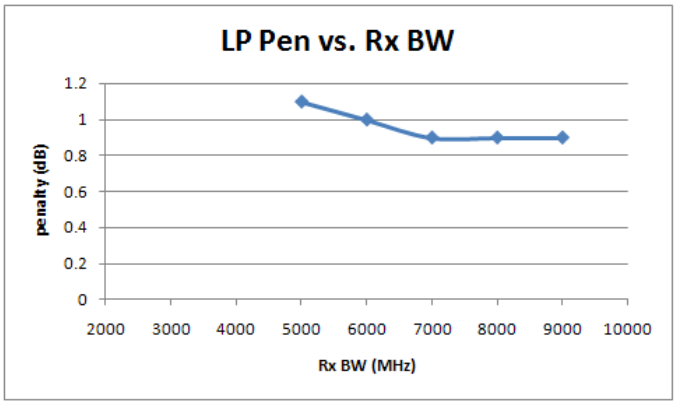
- The link model is populated with key parameter values to represent the Versatile Link operation conditions.
  - MM_VL_proposal
    - *Signal Rate: 5 Gbps*
    - *Target length: 150 m*
    - Center wavelength: 850 nm
    - *RMS spectral width: 0.49 nm*
    - *Ts (20-80): 75ps*
    - Max RIN12OMA: -130 dB/Hz
    - RIN coefficient: 0.70
    - *MPN coefficient: 0.30*
    - *Reflection coefficient: 0*
  - SM_VL_proposal
    - *Signal Rate: 5 Gbps*
    - *Target length: 150 m*
    - Center wavelength: 1310 nm
    - RMS spectral width: 0.20 nm
    - *Ts (20-80): 75ps*
    - Max RIN12OMA: -130 dB/Hz
    - RIN coefficient: 0.70
    - *MPN coefficient: 0*
    - *Reflection coefficient: 0.6*
- Propose to allocate 1.0 dB for MM and 1.5 dB for SM versatile link impairments.

MM_VL Sensitivity Charts



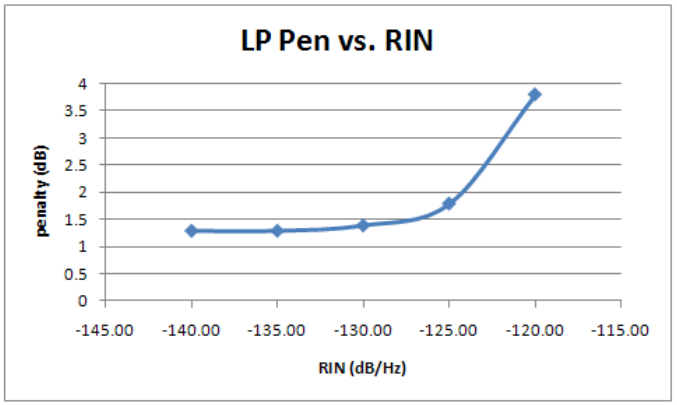


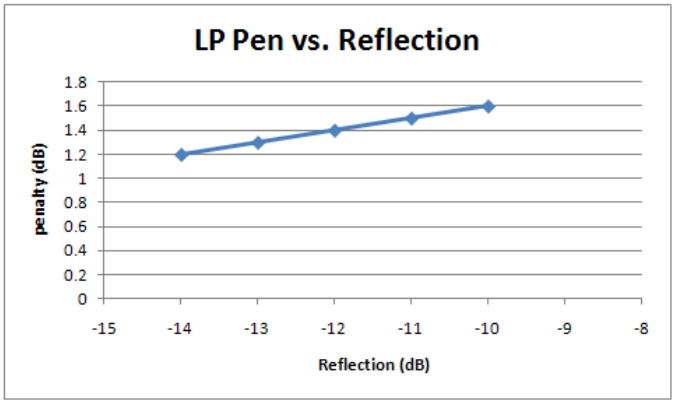


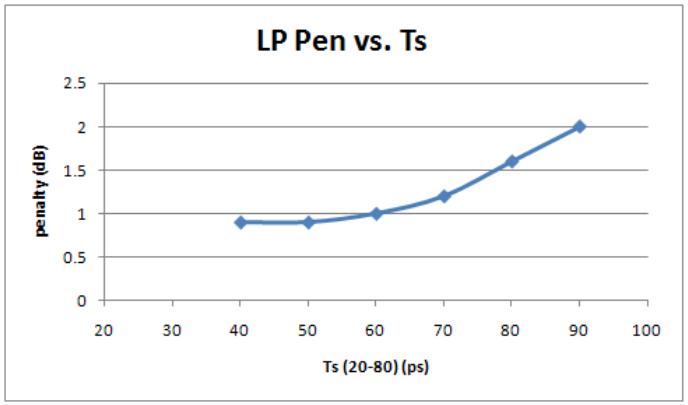


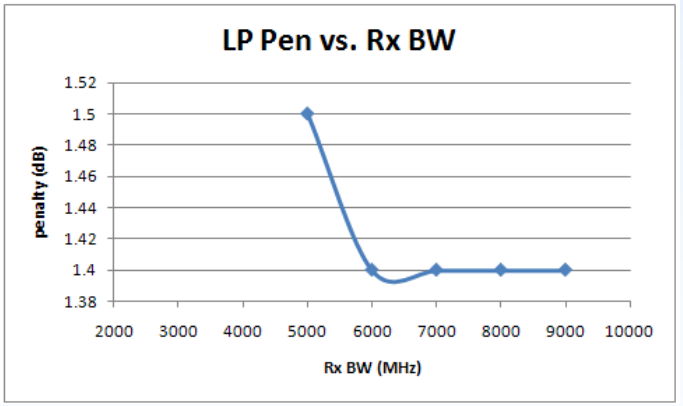
- MM_VL is sensitive to input rise/fall time, insensitive to other parameters within bandwidth limit

SM_VL Sensitivity Charts





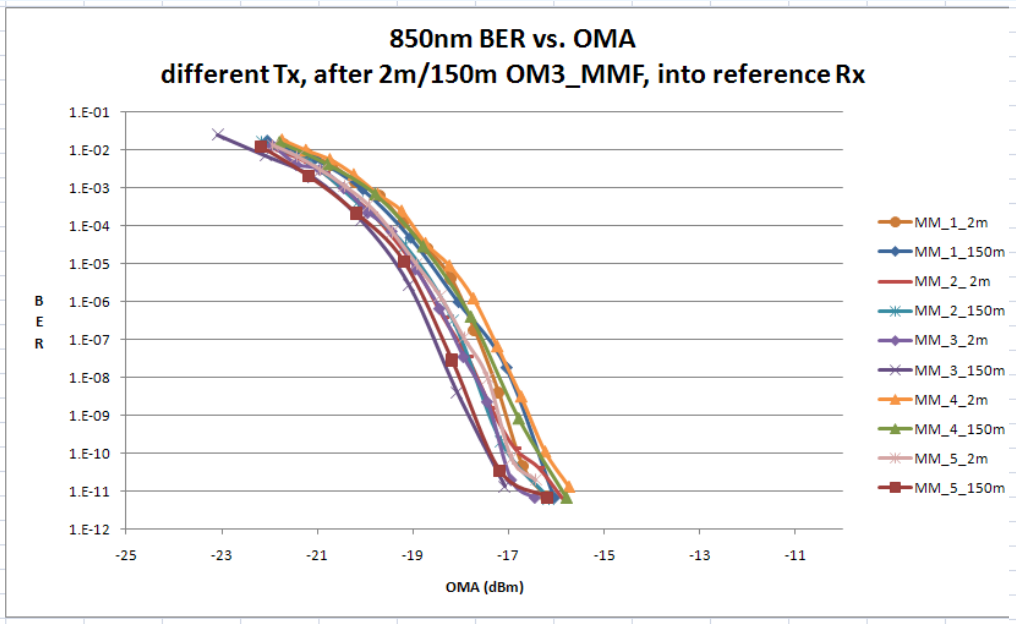


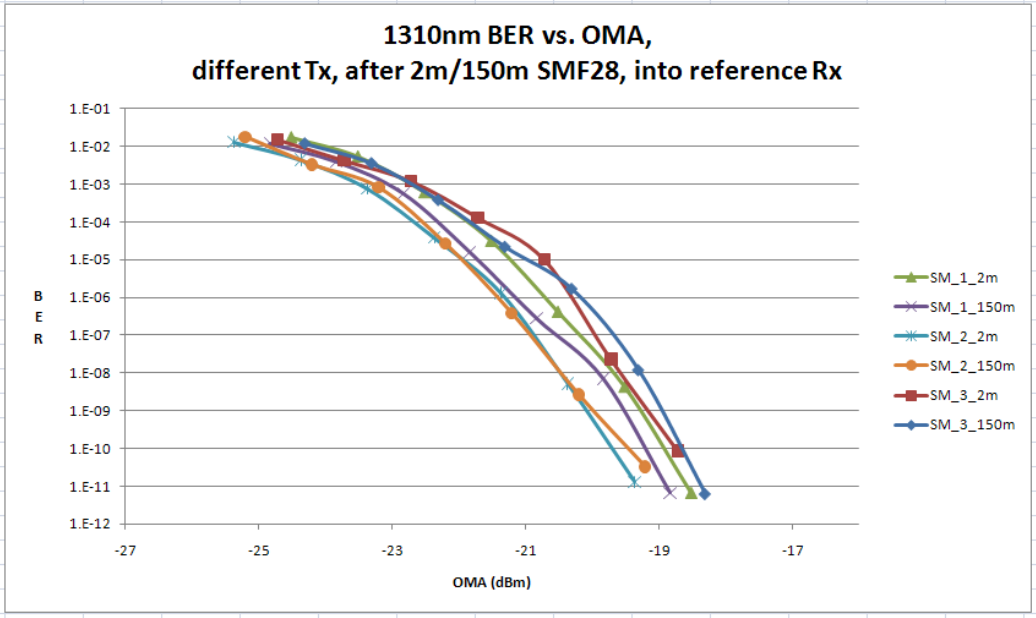


- SM_VL is sensitive to reflection and rise/fall time. In-sensitive to other parameters within a broader bandwidth limit

BER with reference transceivers

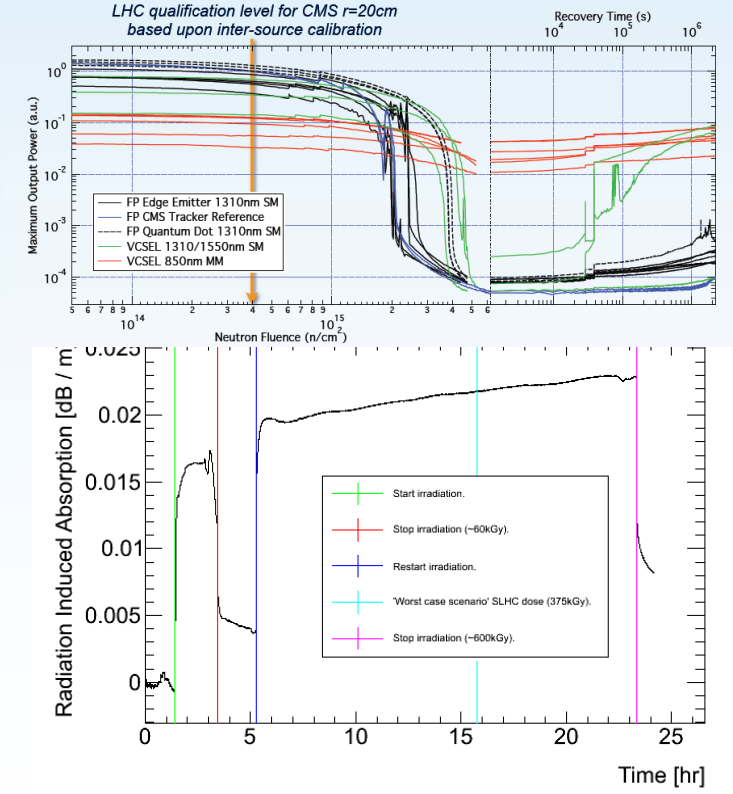
- Power penalty manifest itself as the horizontal shift of the BER curve.
- Several commercial MM/SM transceiver modules are tested for their relative BER differences.
  - Modules from different vendors are tested at 5Gbps
  - Different Tx over 2/150 meter MM/SM fibers into reference Rx.
  - Power penalty differences are below 1.5dB.
  - Differences between modules are larger than differences between link lengths.

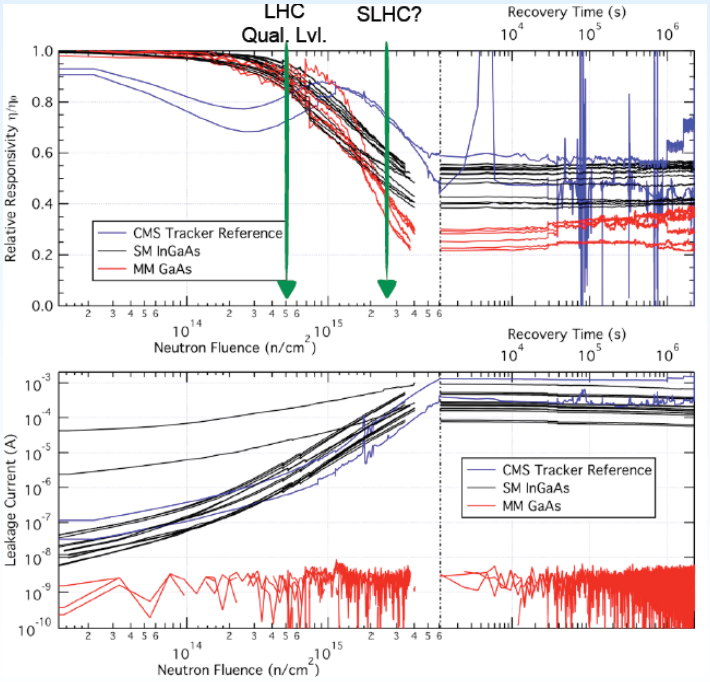




Irradiation effects of link components

- Laser diodes show increased I_{th} and decreased slope efficiency. Both effects anneal.
- InGaAs PIN diodes show increased leakage current. Both InGaAs and GaAs PIN didoes show a degradation in responsivity. Neither effect anneals.
- Different fiber types degrade differently. Radiation resistant candidates performance most optimistic.





- Source: J. Troska et al., 2009; T. Huffman et al., 2010

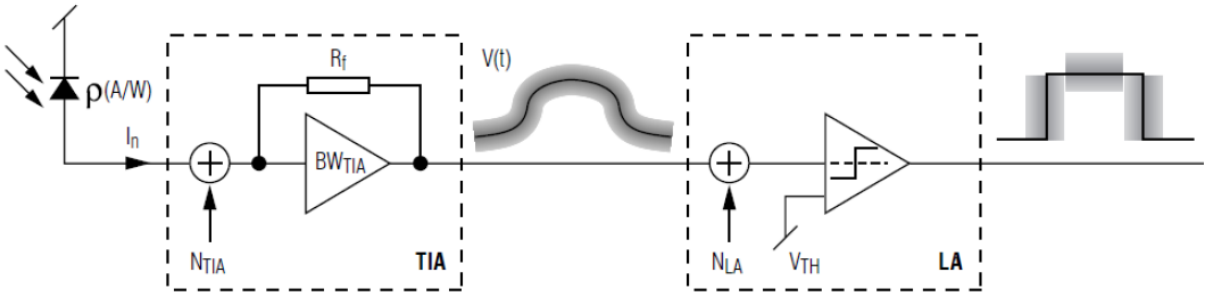
Versatile Link Power Budget

configuration/parameter	MM_VTx_Rx	MM_Tx_VRx	SM_VTx_Rx	SM_Tx_VRx
Transceiver power level				
Tx OMA min	-3.8 dBm	-3.8 dBm	-3.2 dBm	-3.2 dBm
Rx Sensitivity OMA max	-11.1dBm	-11.1dBm	-12.6 dBm	-12.6 dBm
Power budget (Tx - Rx)	7.3 dB	7.3 dB	9.4 dB	9.4 dB
Fiber attenuation	0.6 dB	0.6 dB	0.1 dB	0.1 dB
Connection and splice loss	1.5 dB	1.5 dB	2.0 dB	2.0 dB
Link penalties	1.0 dB	1.0 dB	1.5 dB	1.5 dB
Tx irradiation degradation	-	-	-	-
Rx irradiation degradation	-	7.0 dB	-	9.0 dB
Fiber irradiation degradation	1.0 dB	1.0 dB	-	-
Margin	3.2 dB	-3.8 dB	5.8 dB	-3.2 dB

- Tx power, Rx sensitivity, fiber attenuation, insertion loss assumptions are first aligned with industry examples.
- Link penalties result from simulation.
- Extrapolated sLHC irradiation degradation deduced.
- Two downlinks run deficit.

Versatile Link Preliminary Power Budget

- Power margin can be picked up from transmitter.
  - Tx power is always measured.
  - Tx power is generally balanced by the need to meet eye safety.
- Power margin can also be picked up from receiver.
  - Rx sensitivity measurement is more time consuming.
  - VRx sensitivity will be measured.
  - GBTIA input-referred noise < 20μA
  - Rx sensitivity of -15 dBm (MM) and -17 dBm (SM)



$$N_{TOTAL} = \sqrt{N_{TIA}^2 + \left(\frac{N_{LA}}{R_f}\right)^2}$$

- Source: Maxim-IC, HFAN 3.0.0

Versatile Link Proposed Power Budget

configuration/parameter	MM_VTx_Rx	MM_Tx_VRx	SM_VTx_Rx	SM_Tx_VRx
Transceiver power level				
Tx OMA min	-3.8 dBm	-2.0 dBm	-3.2 dBm	-2.8 dBm
Rx Sensitivity OMA	-11.1dBm	-13.1dBm	-12.6 dBm	-15.4 dBm
Power budget (Tx - Rx)	7.3 dB	7.3 dB	9.4 dB	9.4 dB
Fiber attenuation	0.6 dB	0.6 dB	0.1 dB	0.1 dB
Connection and splice loss	1.5 dB	1.5 dB	2.0 dB	2.0 dB
Link penalties	1.0 dB	1.0 dB	1.5 dB	1.5 dB
Tx irradiation degradation	-	-	-	-
Rx irradiation degradation	-	7.0 dB	-	9.0 dB
Fiber irradiation degradation	1.0 dB	1.0 dB	-	-
Margin	3.2 dB	0.0 dB	5.8 dB	0.0 dB

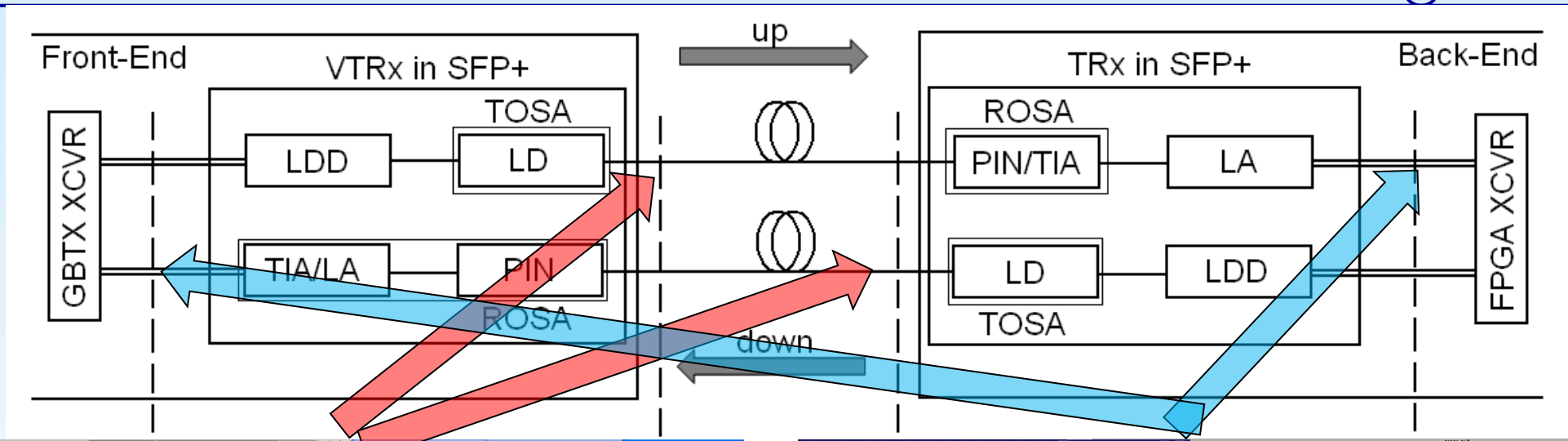
- All links now meet budget.
- Excess uplink power budget allows for higher data rate or longer length.

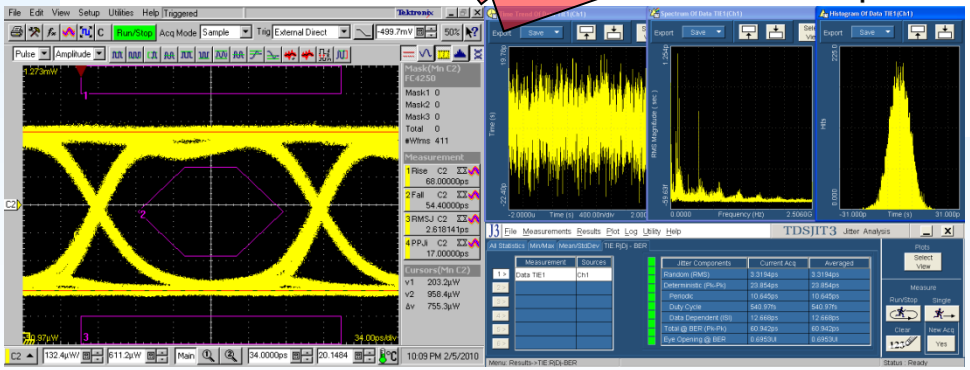
Conclusion

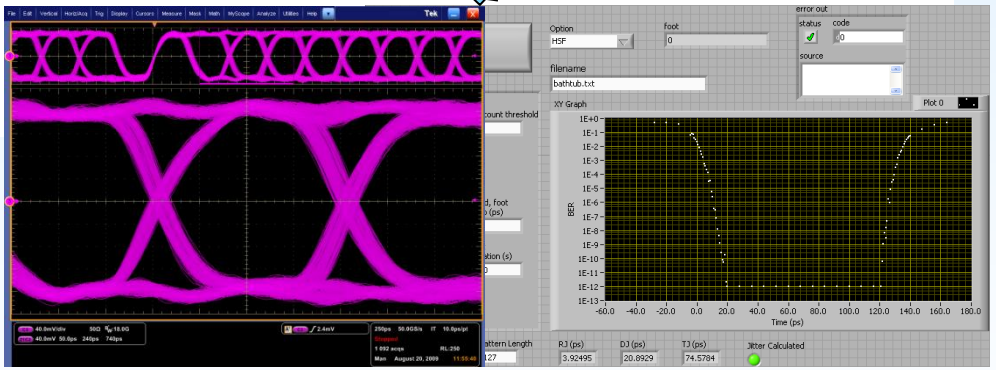
- Power budget of versatile link is achievable
  - The 10Gigabit Ethernet link model has been used with link parameters to provide guidance on setting values of key specifications
  - Measurement results from reference transceivers conform with simulation results
  - In the configurations where extra power is needed, budget can be compensated from back-end transmitter (more stringent specification) and front-end receiver (design targeted TIA specification) with reasonable constrains
- Establish power penalty specification and adding impairments from the link model is a good practice to follow. It gives us confidence that the system will work on a large scale.
- Still need to review:
  - Extending jitter budget into link model
  - Measurement results from versatile transceivers

Thank you for your attention

Versatile Link Specification Methodology







- At the component level, VTRx and TRx need to be tested for
  - Function: interface with GBT and FPGA
  - Signal Integrity: amplitude, noise, timing, jitter and received BER
- Tentative specifications are adapted/modified from 802.3ae, FC-PI-4 and SFF-8431 for electrical and optical interfaces.

Versatile Link Model MM Worksheet

Input portion
Parameters in bold

Spreadsheet by Del Hanson, David Cunningham, Piers Dawe, David Dolfi Agilent Technologies | Rev. 3.2/3 | This file 10GEPBud3_1_16a.xls | of 17-Oct-01

Basics Input= **Bold** | Ts(20-80) 76 ps | Case 850nm serial **newMMF** | Attenuation= **3.5** dB/km | Model/format rev 3.1.16a
Q= **7.04** | Ts(10-90) 115 ps | Target Target reach **0.30** km | Fiber at 850 nm | NomSens OMA **-11.10** dBm | Margin 0.00 dB at
Base Rate= **5000** MBd | RIN(OMA) -130 dB/Hz | and L_start= **0.01** km | C_att= 1.00 | Receive Refl Rx **-12** dB | Answer! 0.3 km
Transmitter | RIN at MinER -139.6 dB/Hz | graph L_inc= **0.01** km | Attenuation= 3.62 dB/km | Rec_BW= **8,250** MHz | est Rx BW **7500** MHz
Wavelength Uc 840 nm | RIN_Coef= **0.70** | Power Budget P= 7.30 dB | at 840 nm | c_rx **329** ns.MHz
Uw (see notes) 0.2? nm | Det Jitter 6.0 ps inc. DCD | Connections C **1.5** dB | Disp. min. Uo= **1320** nm | T_rx(10-90) 39.9 ps | Test Source ER=
Tx pwr OMA= -3.80 dBm | DCD_DJ= 6 ps TP3 | Pwr.Bud.-Conn.Loss 5.8 dB | Disp. So= **0.11** ps/nm^2*km | TP4 Eye 40 ps | Test Tx **6.5** dB
Min. Ext Ratio= 3.00 dB | Effect. DJ= 0.00 (UI) ex DCD | C1= **480** ns.MHz | Disp. D1= -117.76 ps/(nm.km) | Opening (=Tx ey | TestERpe 1.98 dBo
"Worst"ave.TxPwr -2.03 dBm | MPN k(OMA) 0.3 | Reflection Noise factor 0 no units | RMS Baseline wander SD **0.025** fraction of 1/2 eye
Ext. ratio penalty 4.78 dBo | Tx eye height 80.?% | Effective Rate 5155 MBd | (not in use) **10** | V.E.C.P. ##### dBo
Tx mask X1= 0.? UI | RIN... 12 dB | Tb_eff= 194 ps | BWm= **2000** MHz*km | P_BLW(no ISI) 0.07 dB | Stressed
X2= **0.4** UI | ModalNoisePen 0.3 dB | Effective Rec Eye 0.21 UI | Eff. BWm= 2.0E+03 MHz*km | P_BLW 0.07 dB | Rx sens
Y1= **0.25** | Tx mask top 0.2 UI

MM
Center 850nm

Target link length
150meter

Aggregate
Power penalty

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)	Margin (dB)	OMA central (dBm)
0.002	0.01	1.51	-0.24	0.00	3E+06	######	115	122	0.38	0.18	0.00	0.00		-1E-03	0.00	0.00		0.03	0.72	0.90	0.7	5.1	-5.6
0.01	**0.04**	**1.54**	**-1.2**	**0.00**	**547,573**	**200,000**	**115**	**122**	**0.38**	**0.18**	**0.00**	**0.00**	**0**	**-0.01**	**0.00**	**0.00**	**0.11**	**0.05**	**0.9**	**1.0**	**0.8**	**4.9**	**-5.8**
0.02	0.07	1.57	-2.4	0.00	273,787	100,000	115	122	0.38	0.18	0.00	0.00	0	-0.01	0.00	0.00	0.11	0.05	0.9	1.1	0.8	4.9	-5.8
0.03	0.11	1.61	-3.5	0.00	182,524	66,667	116	122	0.38	0.18	0.00	0.00	0	-0.02	0.00	0.00	0.11	0.05	0.9	1.1	0.8	4.9	-5.8
0.04	0.14	1.64	-4.7	0.00	136,893	50,000	116	122	0.38	0.18	0.00	0.00	0	-0.02	0.00	0.00	0.11	0.05	1.0	1.2	0.8	4.8	-5.9
0.05	0.18	1.68	-5.9	0.00	109,515	40,000	116	123	0.39	0.18	0.00	0.00	0	-0.03	0.00	0.00	0.10	0.05	1.0	1.2	0.8	4.8	-5.9
0.06	**0.22**	**1.72**	**-7.1**	**0.00**	**91,262**	**33,333**	**116**	**123**	**0.39**	**0.18**	**0.00**	**0.00**	**0**	**-0.03**	**0.00**	**0.00**	**0.10**	**0.05**	**1.1**	**1.2**	**0.8**	**4.7**	**-5.9**
0.07	0.25	1.75	-8.2	0.00	78,225	28,571	117	123	0.40	0.18	0.00	0.00	0	-0.04	0.00	0.00	0.10	0.05	1.1	1.3	0.8	4.7	-6.0
0.08	0.29	1.79	-9.4	0.00	68,447	25,000	117	124	0.41	0.18	0.00	0.00	0	-0.04	0.00	0.00	0.10	0.05	1.1	1.3	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	60,841	22,222	118	124	0.41	0.18	0.00	0.00	0	-0.05	0.00	0.00	0.10	0.05	1.2	1.4	[illegible]	[illegible]	[illegible]
0.10	0.36	1.86	[illegible]	0.00	54,757	20,000	118	125	0.42	0.18	0.00	0.00	0	-0.06	0.00	0.00	0.09	0.05	1.2	1.4	[illegible]	[illegible]	[illegible]
0.11	**0.40**	**1.90**	**-13.0**	**0.00**	**49,779**	**18,182**	**119**	**125**	**0.43**	**0.18**	**0.00**	**0.00**	**0**	**-0.06**	**0.00**	**0.00**	**0.09**	**0.05**	**1.3**	**1.5**	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	-14.1	0.00	45,631	16,667	119	126	0.44	0.18	0.00	0.00	0	-0.07	0.00	0.00	0.09	0.05	1.3	1.5	0.9	4.5	-6.1
0.13	0.47	1.97	-15.3	0.00	42,121	15,385	120	127	0.45	0.19	0.00	0.00	0	-0.07	0.00	0.00	0.09	0.05	1.4	1.5	0.9	4.4	-6.2
0.14	0.51	2.01	-16.5	0.00	39,112	14,286	121	127	0.46	0.19	0.00	0.00	0	-0.08	0.00	0.00	0.08	0.05	1.4	1.6	0.9	4.4	-6.2
0.15	0.54	2.04	-17.7	0.00	36,505	13,333	122	128	0.48	0.19	0.00	0.00	0	-0.08	0.00	0.00	0.08	0.05	1.5	1.6	0.9	4.3	-6.2
0.16	**0.58**	**2.08**	**-18.8**	**0.00**	**34,223**	**12,500**	**122**	**129**	**0.49**	**0.19**	**0.00**	**0.00**	**0**	**-0.09**	**0.00**	**0.00**	**0.08**	**0.05**	**1.5**	**1.7**	**0.9**	**4.3**	**-6.3**
0.17	0.62	2.12	-20.0	0.00	32,210	11,765	123	130	0.51	0.19	0.00	0.00	0	-0.09	0.00	0.00	0.08	0.05	1.5	1.7	0.9	4.3	-6.3
0.18	0.65	2.15	-21.2	0.00	30,421	11,111	124	130	0.52	0.19	0.00	0.00	0	-0.10	0.00	0.00	0.08	0.05	1.6	1.8	0.9	4.2	-6.4
0.19	0.69	2.19	-22.4	0.00	28,820	10,526	125	131	0.54	0.19	0.00	0.00	0	-0.11	0.00	0.00	0.07	0.05	1.7	1.8	1.0	4.1	-6.4
0.20	0.72	2.22	-23.6	0.00	27,379	10,000	126	132	0.56	0.20	0.00	0.00	0	-0.11	0.00	0.00	0.07	0.05	1.7	1.9	1.0	4.1	-6.4
0.21	**0.76**	**2.26**	**-24.7**	**0.00**	**26,075**	**9,524**	**127**	**133**	**0.58**	**0.20**	**0.00**	**0.00**	**0**	**-0.12**	**0.00**	**0.00**	**0.07**	**0.05**	**1.8**	**2.0**	**1.0**	**4.0**	**-6.5**

- Propose to allocate 1.0 dB for MM versatile link impairments

Versatile Link Model SM Worksheet

Versatile Link

Spreadsheet by Del Hanson, David Cunningham, Piers Dawe, David Dolfi Agilent Technologies									Rev.	3.2/3		This file	10GEPBud3_1_16a.xls		of	17-Oct-01	
Basics Input=	Bold		Ts(20-80)	76	ps	Case: 1310nm serial	SMF		Attenuation=	0.4	dB/km	Model/format rev	3.1.16a		of	31-Oct-01	
Q=	7.04		Ts(10-90)	115	ps	*Target* Target reach	0.15	km	*Fiber* at	1310	nm	NomSens OMA	-12.59	dBm	Margin	5.91	dB at
Base Rate=	5000	MBd	RIN(OMA)	-130	dB/Hz	*and* L_start=	0.01	km	C_att=	0.27		*Receive* Refl Rx	-12	dB	*Answer!*	0.15	km
Transmitter			RIN at MinER	-137.3	dB/Hz	*graph* L_inc=	0.01	km	Attenuation=	0.42	dB/km	Rec_BW=	7,725	MHz	est Rx BW	7500	MHz
Wavelength Uc	1260	nm	RIN_Coef=	0.70		Power Budget P=	9.39	dB	at	1260	nm	c_rx	329	ns.MHz			
Uw (see notes)	0.20	nm	Det.Jitter	6.0	ps inc. DCD	Connections C	2	dB	Disp. min. Uo=	1324	nm	T_rx(10-90)	42.6	ps	Test Source ER=		
Tx pwr OMA=	-3.20	dBm	DCD_DJ=	6	ps TP3	Pwr.Bud.-Conn.Loss	7.39	dB	Disp. So=	0.093	ps/nm^2*km	TP4 Eye	40	ps	*Test Tx*	6	dB
Min. Ext Ratio=	4.00	dB	Effect. DJ=	0.00	(UI) ex DCD	C1=	480	ns.MHz	Disp. D1=	-6.42	ps/(nm.km)	Opening		(=Tx ey	TestERpe	2.23	dBo
"Worst"ave.TxPwr	-2.55	dBm	MPN k(OMA)	0		Reflection Noise factor	0.6	no units				RMS Baseline wander SD	0.025	fraction	of 1/2 eye		
Ext. ratio penalty	3.66	dBo	Tx eye height	80.6%		Effective Rate	5155	MBd	PolMD DGDmax	10	ps at target 0.15km				V.E.C.P.	0.35	dBo
Tx mask X1=	0.3	UI	Refl Tx	-12	dB	Tb_eff=	194	ps	BWm=	1E+06	MHz*km	P_BLW(no ISI)	0.07	dB			Stressed
X2=	0.4	UI	ModalNoisePen	0	dB	Effective Rec Eye	0.21	UI	Eff. BWm=	######	MHz*km	P_BLW	0.07	dB			Rx sens
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)	Margin (dB)	OMA central (dBm)
0.002	0.00	2.00	-0.01	0.00	7E+07	######	115	123	0.39	0.18	0.00	0.00		-4E-05	0.00	0.00		0.02	0.41	0.59	0.4	7.0	-11.1
0.01	**0.00**	**2.00**	**-0.1**	**0.00**	**14,561,481**	**500,000**	**115**	**123**	**0.39**	**0.18**	**0.00**	**0.00**	**0.82**	**0.00**	**0.00**	**0.00**	**0.15**	**0.06**	**1.4**	**1.6**	**1.4**	**6.0**	**-12.1**
0.02	0.01	2.01	-0.1	0.00	7,280,741	250,000	115	123	0.39	0.18	0.00	0.00	0.82	0.00	0.00	0.00	0.15	0.06	1.4	1.6	1.4	6.0	-12.1
0.03	0.01	2.01	-0.2	0.00	4,853,827	166,667	115	123	0.39	0.18	0.00	0.00	0.81	0.00	0.00	0.00	0.15	0.06	1.4	1.6	1.4	6.0	-12.1
0.04	0.02	2.02	-0.3	0.00	3,640,370	125,000	115	123	0.39	0.18	0.00	0.00	0.81	0.00	0.00	0.00	0.15	0.06	1.4	1.6	1.4	6.0	-12.1
0.05	0.02	2.02	-0.3	0.00	2,912,296	100,000	115	123	0.39	0.18	0.00	0.00	0.81	0.00	0.00	0.00	0.15	0.06	1.4	1.6	1.4	5.9	-12.1
0.06	**0.03**	**2.03**	**-0.4**	**0.00**	**2,426,914**	**83,333**	**116**	**123**	**0.39**	**0.18**	**0.00**	**0.00**	**0.81**	**0.00**	**0.00**	**0.00**	**0.15**	**0.06**	**1.4**	**1.6**	**1.4**	**5.9**	**-12.1**
0.07	0.03	2.03	-0.4	0.00	2,080,212	71,429	116	123	0.40	0.18	0.00	0.00	0.81	0.00	0.00	0.00	0.15	0.06	1.4	1.6	1.4	5.9	-12.1
0.08	0.03	2.03	-0.5	0.00	1,820,185	62,500	116	123	0.40	0.18	0.00	0.00	0.81	0.00	0.00	0.00	0.15	0.06	1.5	1.6	1.4	5.9	-12.1
0.09	0.04	2.04	-0.6	0.00	1,617,942	55,556	116	123	0.40	0.18	0.00	0.00	0.81	0.00	0.00	0.00	0.15	0.06	1.5	1.6	1.4	5.9	-12.1
0.10	0.04	2.04	-0.6	0.00	1,456,148	50,000	116	123	0.40	0.18	0.00	0.00	0.81	0.00	0.00	0.00	0.15	0.06	1.5	1.6	1.4	5.9	-12.1
0.11	**0.05**	**2.05**	**-0.7**	**0.00**	**1,323,771**	**45,455**	**116**	**123**	**0.40**	**0.18**	**0.00**	**0.00**	**0.81**	**0.00**	**0.00**	**0.00**	**0.15**	**0.06**	**1.5**	**1.6**	**1.4**	**5.9**	**-12.1**
0.12	0.05	2.05	-0.8	0.00	1,213,457	41,667	116	124	0.40	0.18	0.00	0.00	0.81	0.00	0.00	0.00	0.15	0.06	1.5	1.6	1.4	5.9	-12.1
0.13	0.05	2.05	-0.8	0.00	1,120,114	38,462	116	124	0.40	0.18	0.00	0.00	0.81	0.00	0.00	0.00	0.15	0.06	1.5	1.7	1.4	5.9	-12.1
0.14	0.06	2.06	-0.9	0.00	1,040,106	35,714	116	124	0.40	0.18	0.00	0.00	0.81	0.00	0.00	0.00	0.15	0.06	1.5	1.7	1.4	5.9	-12.2
0.15	0.06	2.06	-1.0	0.00	970,765	33,333	116	124	0.41	0.18	0.00	0.00	0.81	0.00	0.00	0.00	0.14	0.06	1.5	1.7	1.4	5.9	-12.2
0.16	**0.07**	**2.07**	**-1.0**	**0.00**	**910,093**	**31,250**	**116**	**124**	**0.41**	**0.18**	**0.00**	**0.00**	**0.81**	**0.00**	**0.00**	**0.00**	**0.14**	**0.06**	**1.5**	**1.7**	**1.4**	**5.9**	**-12.2**
0.17	0.07	2.07	-1.1	0.00	856,558	29,412	117	124	0.41	0.18	0.00	0.00	0.81	0.00	0.00	0.00	0.14	0.06	1.5	1.7	1.4	5.9	-12.2
0.18	0.08	2.08	-1.2	0.00	808,971	27,778	117	124	0.41	0.18	0.00	0.00	0.80	0.00	0.00	0.00	0.14	0.06	1.5	1.7	1.4	5.9	-12.2
0.19	0.08	2.08	-1.2	0.00	766,394	26,316	117	124	0.41	0.18	0.00	0.00	0.80	0.00	0.00	0.00	0.14	0.06	1.5	1.7	1.4	5.9	-12.2
0.20	0.08	2.08	-1.3	0.00	728,074	25,000	117	124	0.42	0.18	0.00	0.00	0.80	0.00	0.00	0.00	0.14	0.06	1.5	1.7	1.4	5.9	-12.2
0.21	**0.09**	**2.09**	**-1.3**	**0.00**	**693,404**	**23,810**	**117**	**125**	**0.42**	**0.18**	**0.00**	**0.00**	**0.80**	**0.00**	**0.00**	**0.00**	**0.14**	**0.06**	**1.5**	**1.7**	**1.4**	**5.9**	**-12.2**

- Propose to allocate 1.5 dB for SM versatile link impairments