100G PSM4 Link Model Results Update

John Petrilla: Avago Technologies

January 2013

Contributor & Supporters

Contributor	
David Cunningham	Avago Technologies
Supporters	
Brian Welch	Luxtera
Chris Bergey	Luxtera
Jon Anderson	Oclaro

100G PSM4 Link Model Results Update

Presentation Objectives:

- Update set of attribute values for 100G PSM4, 500 m SMF, example link model
  - Reduced target reach from 2 km to 500 m
  - Increased connector and splice loss allocation from 2.0 dB to 3.0 dB
  - Update of KR4 FEC benefit based on anslow_01_1112_mmf_draft_1
- Provide comparison with link models attributes for 10GBASE-LR and 100GBASE-LR4
- Show tradeoff between connector loss and SMF reach

Conclusions:

- Capturing the benefits of KR4 FEC offers cost reduction opportunities that are not available to 100GBASE-LR4.
- A robust insertion loss budget at the 500 m SMF reach objective offers flexibility where longer reaches are desired.
- The 10GbE based example link model sufficiently addresses adverse effects of MPI.

Fiber Optic Links Interfaces

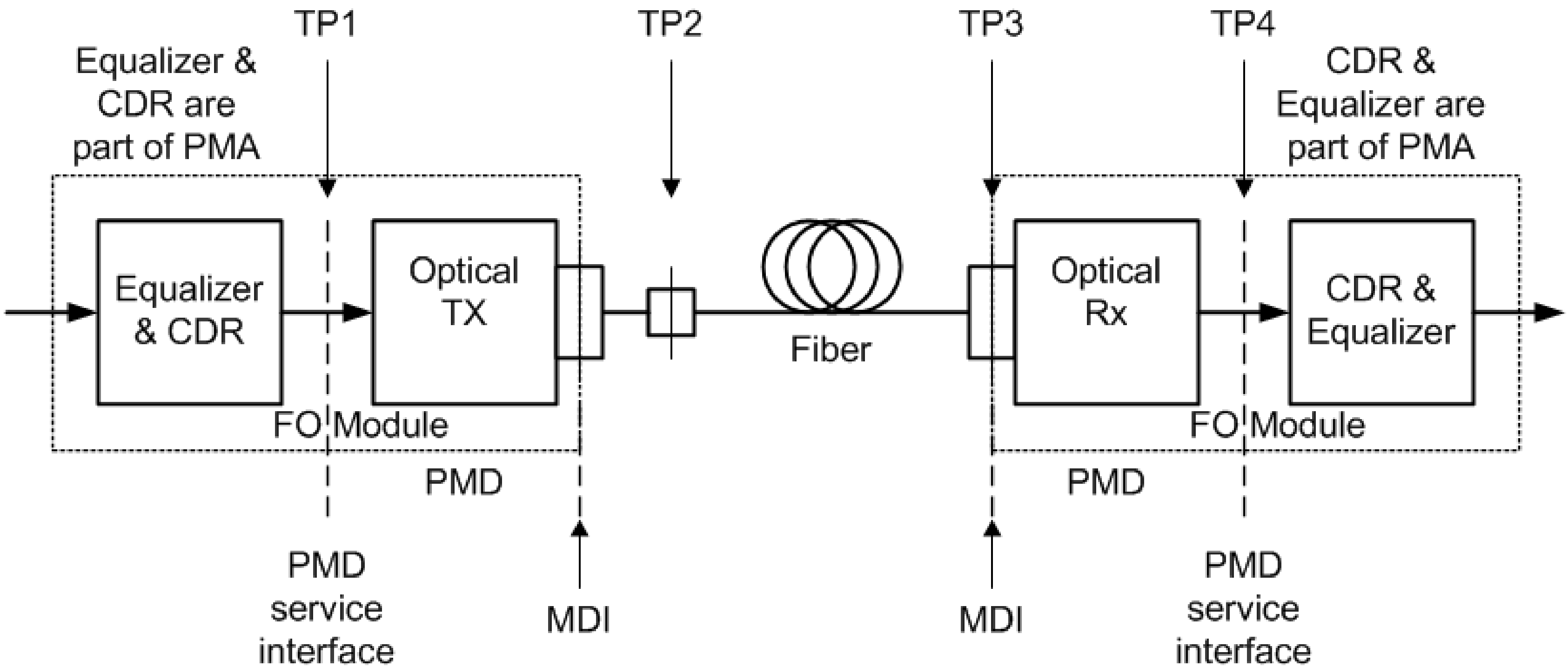


Figure 1

- For cases, as shown above in Figure 1, where retimers are incorporated in the optical module, the PMD service interface is not exposed. TP1 and TP4 remain as points on the PMD service interface and, consequently not exposed.
- The high speed signal inputs and outputs of the optical module are expected to be defined by CAUI-4.

100G PSM4 Link Model: FEC Update

Optical Link

•KR4 FEC enables reduction of Q for the SMF link from Qo = 7.034 for a BER = 10^{-12} to Qi = 3.8905 for a BER = 5.0×10^{-5} enhancing Rx sensitivity by 10Log(Qo/Qi) = 2.57 dB, providing a larger signal power budget.

•FEC benefit is used to reduce Tx signal level, loosen other Tx (ER) and Rx (Sensitivity and Optical Return Loss) requirements and increase connector loss allocation permitting cheaper and lower power consuming devices.

•Sensitivity based measurements (e.g. TDP and SRS) can be simpler, quicker and cheaper for a 5.0×10^{-5} BER than for a 10^{-12} BER.

CAUI-4

•Expected to be defined as not relying on FEC & operating at a BER = 10^{-12} or better.

CAUI-4 – PSM4 – CAUI-4 Link

•Maintains signal and Baud rate of NRZ, 64b/66b encoded, 25.78125 Gb/s signal

100G PSM4 with KR4 FEC: Tx Link Model Attributes (each lane)

Parameter	Unit	10G LR	100G LR4	100G PSM4	
Signal rate	GBd	10.3125	25.78125		
Q (BER)		7.034 (E-12)		3.8905 (5E-5)	KR4 FEC corrects PSM4 BER to ≤ E-12
Center Wavelength, min	nm	1260	1294.53	1295	
Center Wavelength Range, max	nm	95	2.1	30	
Spectral Width, max	nm	0.20			Note 1
OMA at max TDP & w.l. offset, min	dBm	-3.0	-0.1	-3.1	Note 2
Extinction ratio, min	dB	3.5	4.0	3.5	
Tx output transition times, 20% -80%, max	ps	47.0	12	18	
RINcOMA, max	dB/Hz	-128	-130	-128	Note 3
RIN coefficient		0.7			
Tx reflectance, max	dB	-12			
Tx optical return loss tolerance, max	dB	12	20	12	

Attributes and values in the above table are provided in order to populate example link models and are not presented as specification recommendations.

Note 1, Model uses 0.2 nm spectral width to generate penalty equivalent to max expected from chirp.

Note 2, Trade-offs are available for min OMA, center wavelength and TDP. Reference to be named.

Note 3, For 10G LR & 100G PSM4, c = 12 and for 100G LR4, c = 20.

100G PSM4 with KR4 FEC: Rx Link Model Attributes (each lane)

Parameter	Unit	10G LR	100G LR4	100G PSM4	
Signal rate	GBd	10.3125	25.78125		
Q (BER)		7.034 (E-12)		3.8905 (5E-5)	KR4 FEC corrects PSM4 BER to ≤ E-12
Center Wavelength, min	nm	1260	1294.53	1295	
Center Wavelength Range, max	nm	95	2.1	30	
Rx sensitivity (OMA), max	dBm	-12.6	-8.6	-9.46 (-6.89 at Q = 7.034)	
Rx Bandwidth, min	MHz	7734	19,336		
RMS base line wander coefficient	dB/Hz	0.025			
Rx reflectance, max	dB	-12	-26	-12	

Attributes and values in the above table are provided in order to populate example link models and are not presented as specification recommendations.

100G PSM4 with KR4 FEC: Link Model Channel Attributes (each lane)

Parameter	Unit	10G LR	100G LR4	100G PSM4	
Signal rate	GBd	10.3125	25.78125		
Q (BER)		7.034 (E-12)		3.8905 (5E-5)	KR4 FEC corrects PSM4 BER to ≤ E-12
Reach	km	10	10	0.5	
Fiber Attenuation	dB/km	0.40	0.424		For 1310 nm center wavelength
Dispersion, min Uo	nm	1324			
Dispersion, So	ps/nm^{2}km	0.093			
PolMD DGD max	ps	10	10	2.24	Sq root dependency with length
Reflection Noise Factor		0.6			
Signal power budget at max TDP	dB	9.6	8.50	6.36	Model output
Connector & splice loss allocation	dB	2.0	2.0	3.0	
Fiber Insertion loss	dB	4.20	4.30	0.21	Model output
Allocation for penalties at max TDP	dB	3.26	1.93	2.77	Model output
Allocation for target eye at max TDP	dB	0.14	0.27	0.38	Model output
Additional insertion loss allowed	dB	0.0	0.0	0.0	Model output

Attributes and values in the above table are provided in order to populate example link models and are not presented as specification recommendations. Various model outputs are provided as examples.

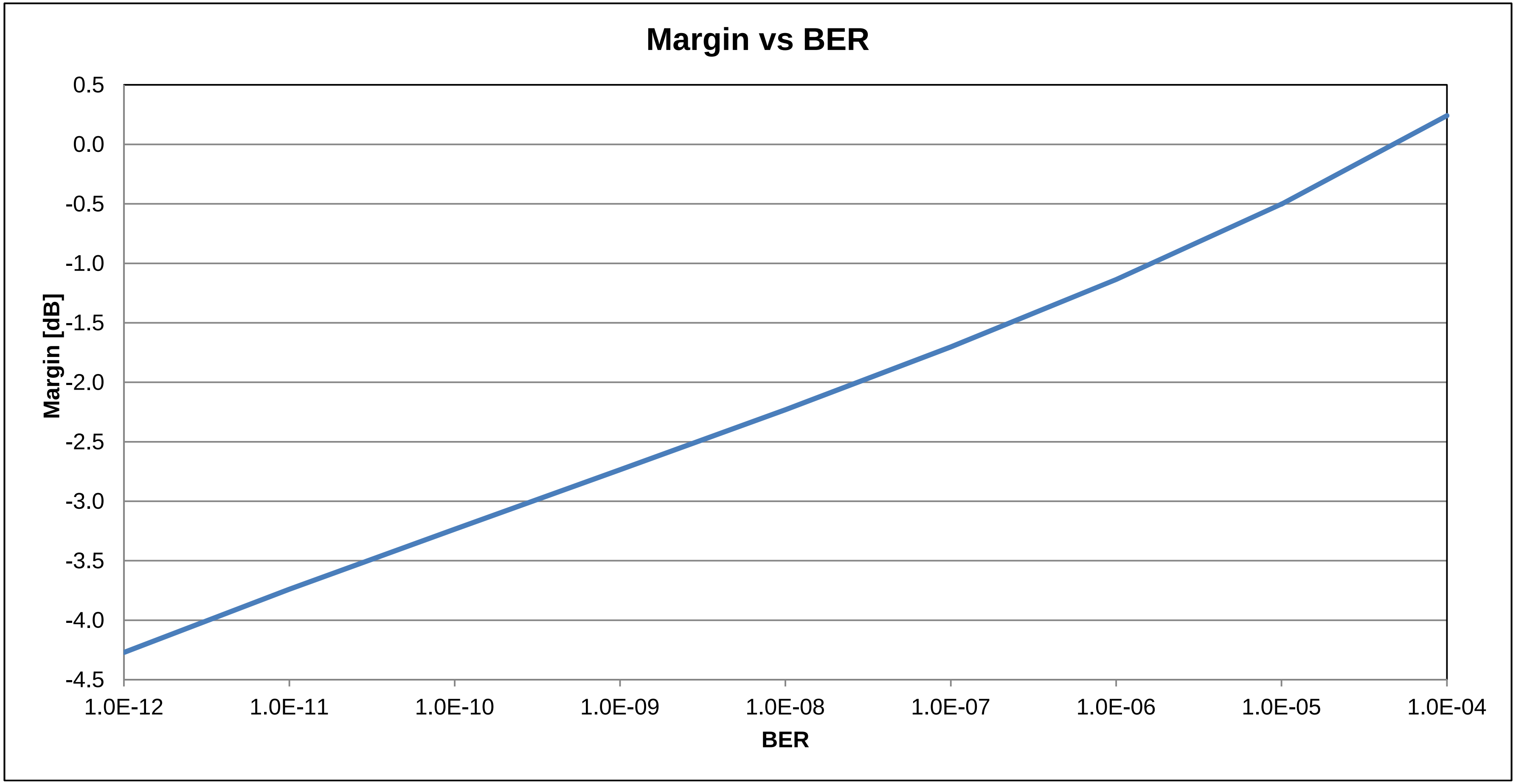
100G PSM4 with KR4 FEC: Link Model Jitter Attributes (each lane)

Parameter	Unit	10G LR	100G LR4	100G PSM4	
Signal rate	GBd	10.3125	25.78125		
Q (BER)		7.034 (E-12)		3.8905 (5E-5)	KR4 FEC corrects PSM4 BER to ≤ E-12
TP1 RJrms tolerance, min	UI	0.0036	0.0054	0.0079	
TP1 DJ tolerance, min	UI	0.083	0.087	0.110	
TP3 DCD tolerance, min	UI	0.0619	0.05	0.050	
TP3 DJ tolerance, min	UI	0.083	0.087	0.150	
TP4 J2, max	UI	0.376	0.359	0.419	Model output
TP4 TJ at BER, max	UI	0.900	0.850	0.900	Model output

Attributes and values in the above table are provided in order to populate example link models and are not presented as specification recommendations.   Various model outputs are provided as examples.

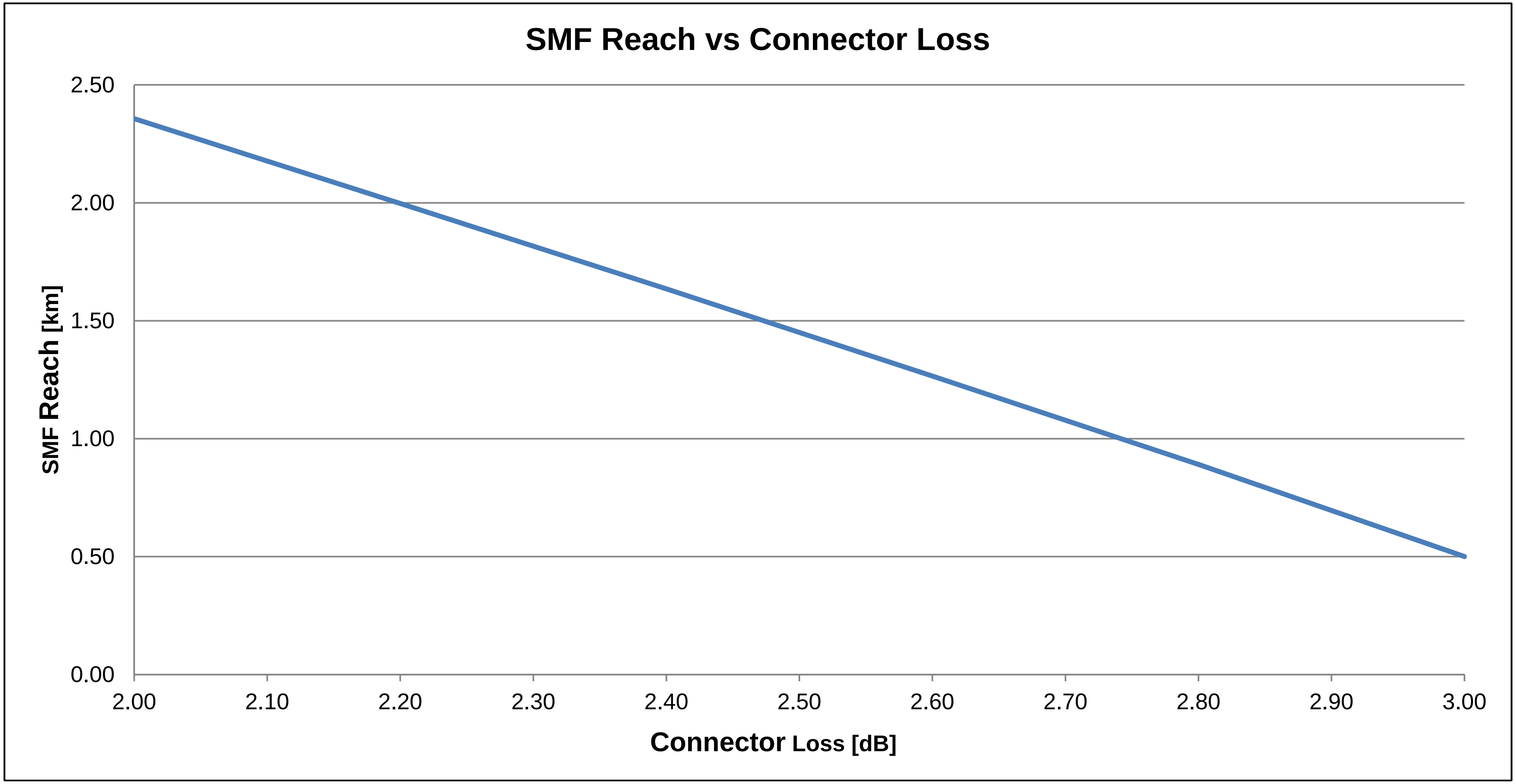
Nomenclature: Terms TP1, TP2, TP3 and TP4 are used as defined in 802.3 clause 88 and shown in above Figure 1. Note that TP1 is downstream of the input CDR and equalizer for an optical transmitter.

100G PSM4: Benefit from KR4 FEC



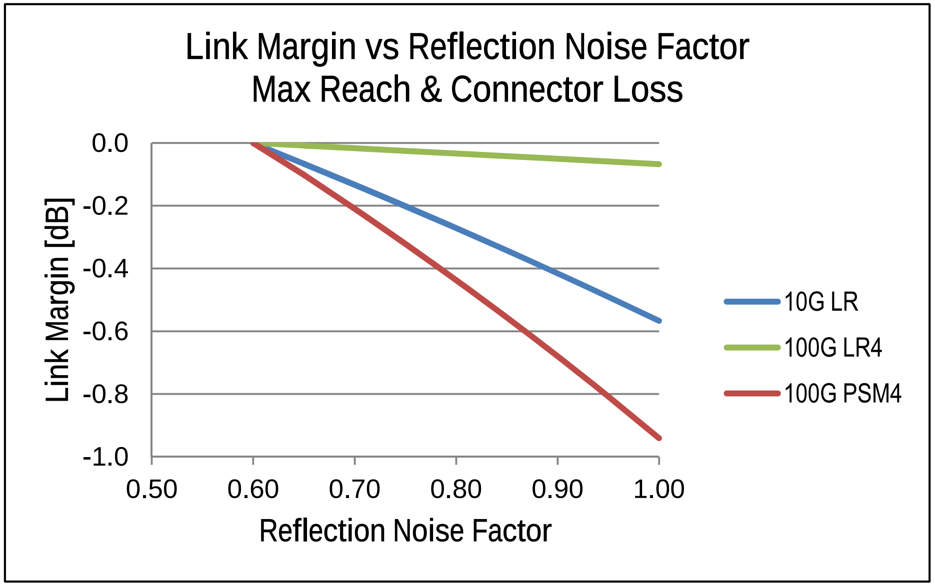
The above chart shows the benefit to an optical link from FEC. Operating at a higher BER not only appears to improve the Rx sensitivity but all the noise related penalties are reduced as is the power required to open the eye to a target width. For 100G PSM4, capturing all the benefit of KR4 FEC (operation at a BER = 5 x 10^{-5}) enhances the link margin by ~4.3 dB when compared to operating at a BER = 10^{-12} without FEC.

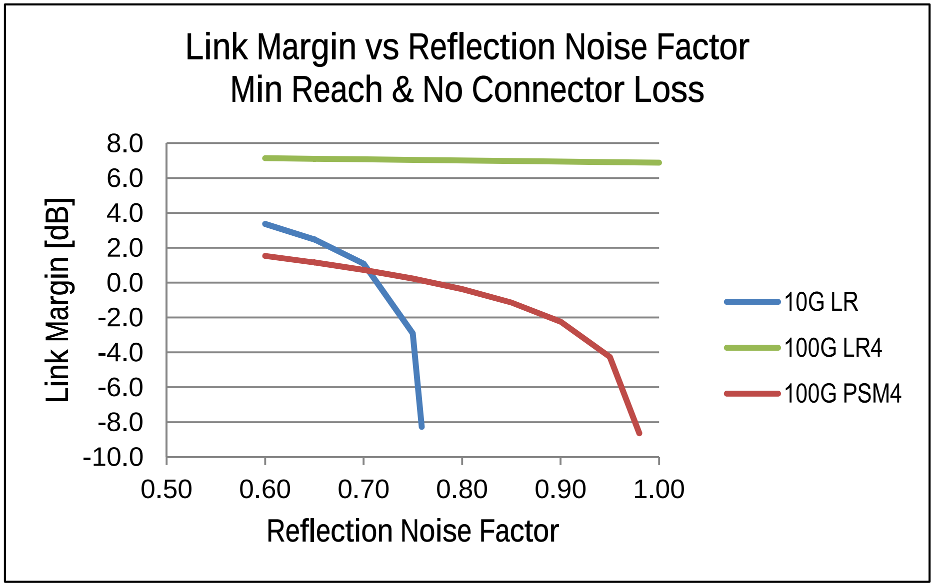
100G PSM4 with KR4 FEC: SMF Reach Tradeoff with Connector Loss



The above chart shows the tradeoff available between SMF reach and connector loss.

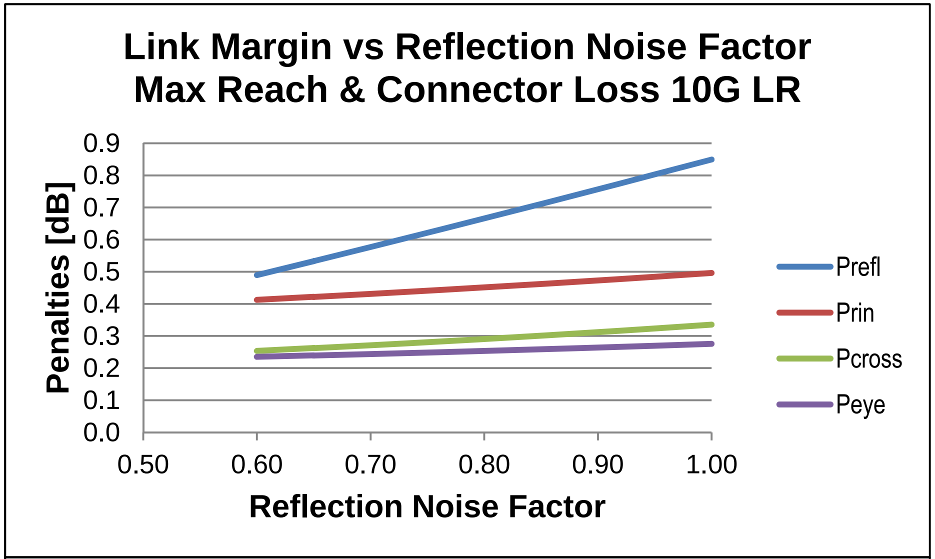
100G PSM4, 10G LR & 100G LR4 Link Margin vs Reflection Noise Factor

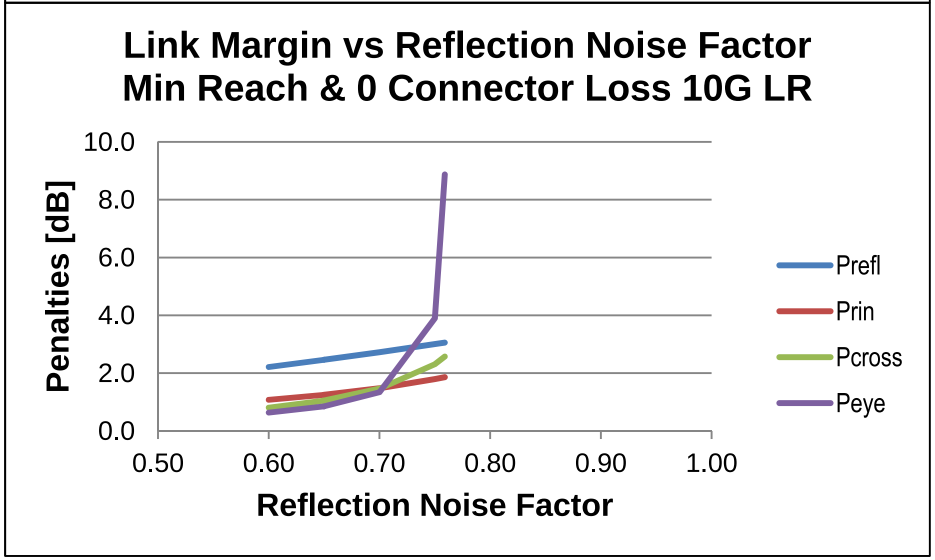




- The example link model for 100G PSM4 has a value of 0.6 for the Reflection Noise Factor (Refl NF). This value has been used since the spread sheet was introduced in October 2001. Here and on following pages, sensitivity to the Refl NF is explored. For a reality check, the exploration includes 10G LR which was one of the variants defined with the initial use of the link model.
- Three cases, 10G LR, 100G LR4 and 100G PSM4 were examined at max loss and min loss conditions.
- For the 10G LR and 100G LR4 cases, the worst case Tx is defined by TDP requirements and the worst case Rx is defined by SRS requirements.
- For 100G PSM4, the worst case Tx and Rx are defined in the Link Module Attribute tables.
- All cases show zero margin at max loss and reach for a Rfl NF set at 0.6 and negative margin for higher values. 100G LR4 shows the lowest sensitivity to Rfl NF and 100G PSM4 shows the highest.
- For min reach and loss, 10G LR show catastropic margin loss for Rfl NF > 0.75. As above, 100G LR4 shows the least sensitivity to Rfl NF.

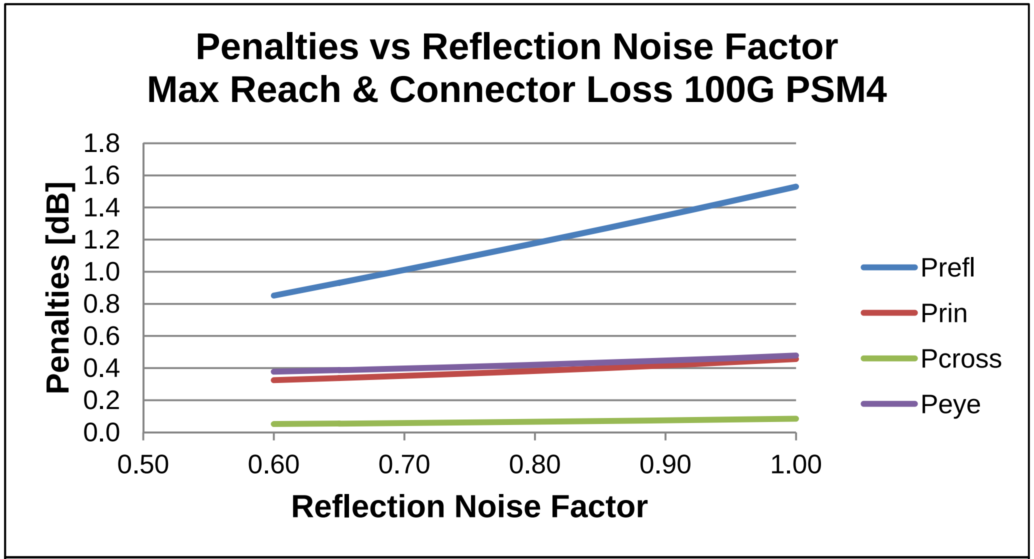
10G LR Penalties vs Reflection Noise Factor

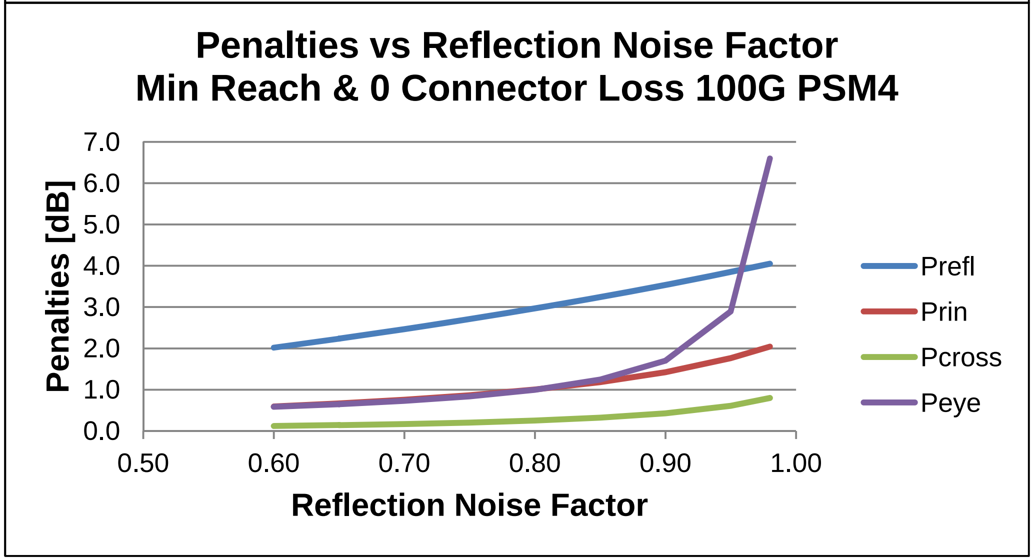




These charts show that in the link model, since reflections are treated as a source of ISI, other penalties, Prin, Pcross and Peye, are dependent on the Reflection Noise Factor enhancing the aggregate effect. This enhancement can be dramatic as shown in the figure for the min reach and loss case.

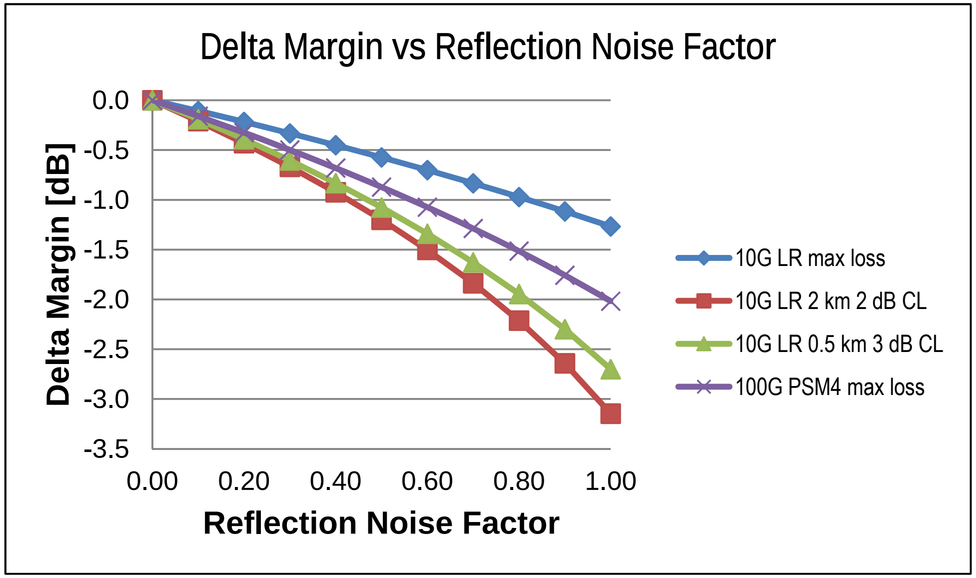
100G PSM4 Penalties vs Reflection Noise Factor





- These charts again show that 100G PSM4 is not as sensitive to larger values of Refl NF as is 10G LR but still shows a catastrophic loss of margin as Refl NF approaches unity.

10G LR & 100G PSM4 Penalties vs Reflection Noise Factor



- This chart shows that for similar loss and reaches, 100G PSM4 is not as sensitive to Refl NF as is 10G LR. For reference the max loss case for 100G PSM4 is 0.5 km with 3 dB connector loss.
- If the industry experience with 10G LR has been satisfactory, is there any need to change the link model?
- If there's no need to change the model for 10G LR, is changing the model for 100G PSM sensible?

Reflection Penalties: Low Loss Cases

Case	Reach	Channel IL	Tx Refl	Rx Refl	In Line Refl	ER	Link Model Margin (Refl NF = 0.6)	Link model Delta Margin Margin[Refl NF = 0] – Margin[Refl NF = 0.6]	Upper Bound Penalty
10G LR	2 m	0	12	12	100	3.5	3.36	4.10	2.65
100G PSM4	2 m	0	12	12	100	3.5	1.54	2.78	2.65
100G LR4	2 m	0	12	26	100	4.0	7.13	0.34	0.38
10G LR	500 m	0.21	12	12	100	3.5	3.53	3.71	2.48
100G PSM4	500 m	0.21	12	12	100	3.5	1.48	2.60	2.48
100G LR4	500 m	0.21	12	26	100	4.0	6.91	0.33	0.36
10G LR	500 m	0.21	12	12	55	3.5	3.07	4.17	2.67
100G PSM4	500 m	0.21	12	12	55	3.5	1.25	2.83	2.67
100G LR4	500 m	0.21	12	26	55	4.0	6.86	0.38	0.41
10G LR	500 m	0.21	12	12	35	3.5	Off scale	Off scale	5.14
100G PSM4	500 m	0.21	12	12	35	3.5	-2.95	7.03	5.14
100G LR4	500 m	0.21	12	26	35	4.0	6.38	0.86	0.93

- Penalties using the MPI Upper-Bound penalty from bhatt_01_0512 (http://www.ieee802.org/3/100GNGOPTX/public/may12/bhatt_01_0512_optx.pdf) are compared in the above table with penalties from the example link model for various case of 10G LR, 100G LR4 and 100G PSM4.
- For the Bhatt Upper-Bound penalty calculations, PAM2, four inline connectors in addition to the connectors at the module interface are assumed. Independent variables are: channel insertion loss, return loss of the module connectors, return loss of the inline connectors and ER.
- Since the example link model does not accommodate inline connectors, for the < 100 dB inline connector cases, Tx Refl and Rx Refl values (not shown above) were adjusted to provide an equivalence using the Bhatt Upper-Bound penalty calculations.
- Inline connector reflections greater than -55 dB do not apply where MPO connectors are used.
- For the low loss cases in the above table, it can be seen that the example link model estimates higher penalties than the Bhatt Upper-Bound penalty calculations except for 100G LR4 where the penalty is inconsequential. Also, 100GPSM4 always shows positive margin except where the connector would be out of spec and for this case tolerates the connector better than 10G LR.

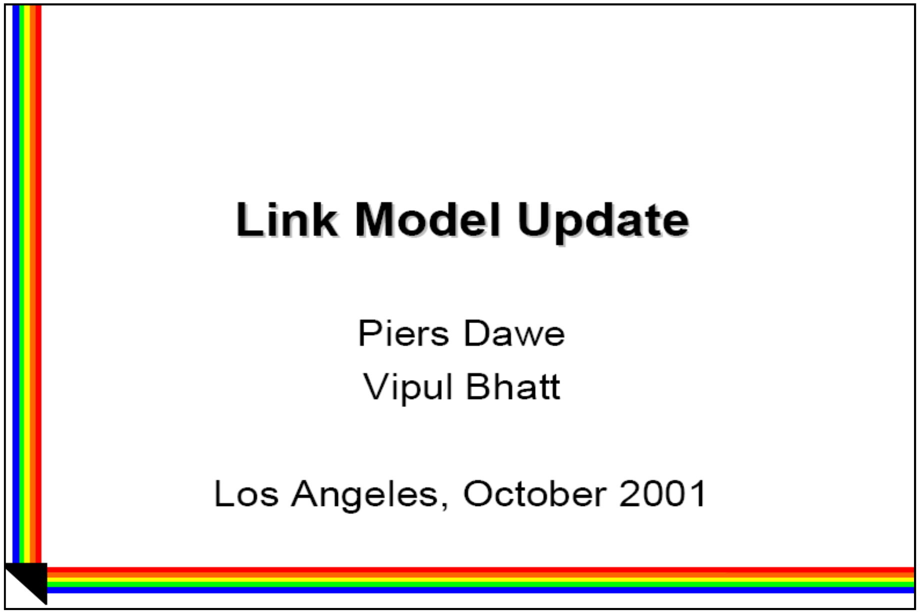
Reflection Penalties: High Loss Cases

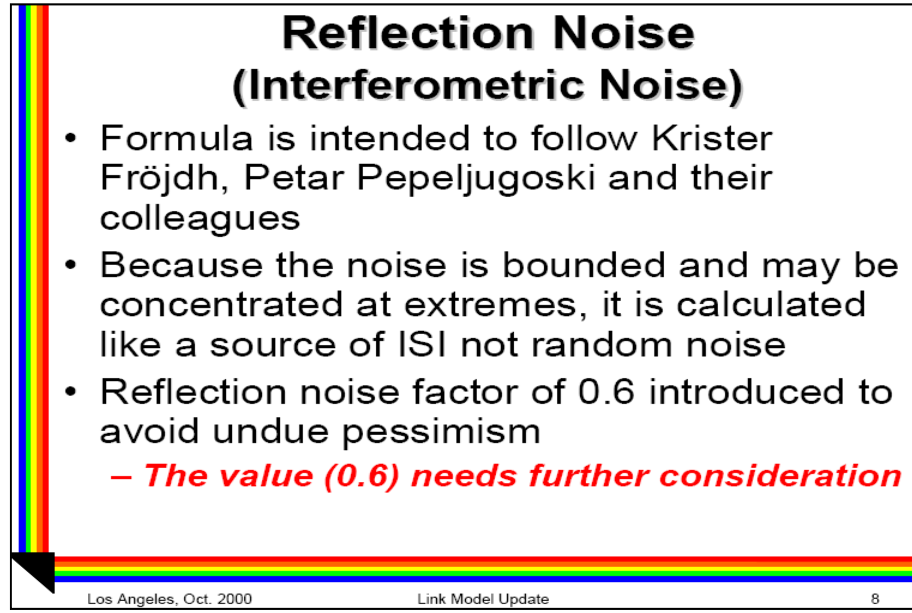
Case	Reach	Channel IL	Tx Refl	Rx Refl	In Line Refl	ER	Link Model Margin (Refl NF = 0.6)	Link model Delta Margin Margin[Refl NF = 0] – Margin[Refl NF = 0.6]	Upper Bound Penalty
10G LR	500 m	2.21	12	12	100	3.5	3.44	1.80	1.39
100G PSM4	500 m	2.21	12	12	100	3.5	0.67	1.41	1.39
100G LR4	500 m	2.21	12	26	100	4.0	5.03	0.21	0.22
10G LR	500 m	2.21	12	12	55	3.5	3.30	1.94	1.49
100G PSM4	500 m	2.21	12	12	55	3.5	0.57	1.51	1.49
100G LR4	500 m	2.21	12	26	55	4.0	5.01	0.23	0.25
10G LR	500 m	2.21	12	12	35	3.5	1.48	3.76	2.50
100G PSM4	500 m	2.21	12	12	35	3.5	-0.55	2.63	2.50
100G LR4	500 m	2.21	12	26	35	4.0	4.72	0.52	0.56
10G LR	500 m	3.21	12	12	100	3.5	2.90	1.34	1.07
100G PSM4	500 m	3.21	12	12	100	3.5	0	1.08	1.07
100G LR4	500 m	3.21	12	26	100	4.0	4.08	0.16	0.18
10G LR	500 m	3.21	12	12	55	3.5	2.81	1.43	1.14
100G PSM4	500 m	3.21	12	12	55	3.5	-0.07	1.15	1.14
100G LR4	500 m	3.21	12	26	55	4.0	4.05	0.19	0.20
10G LR	500 m	3.21	12	12	35	3.5	1.72	2.52	1.86
100G PSM4	500 m	3.21	12	12	35	3.5	-0.83	1.91	1.86
100G LR4	500 m	3.21	12	26	35	4.0	3.83	0.41	0.44

•For the high loss cases in the above table, as with the low loss cases, the example link model estimates higher penalties than the Bhatt Upper-Bound penalty calculations. Again, the 35 dB inline connector cases do not apply where MPO connectors are used.

•The conservatism of the worst case based 10GbE link model appears to adequately address adverse MPI effects.

Link Model Background (1 of 2)





To provide background, pages are copied from the "Link Model Update", http://www.ieee802.org/3/ae/public/oct01/dawe_1_1001.pdf where the reflection noise penalty was introduced into the 10GbE link model and shown here and on the following page. The reflection noise penalty is calculated (in dB) according to the following expression

$$P_r = -10 \cdot \log\left[1 - \frac{2 \cdot R_{NF} \cdot 10^{\frac{-ChIL}{10}} \cdot GMR \cdot \sqrt{1 + \varepsilon + 2 \cdot \varepsilon \cdot O(DJ_{eff}) \cdot (\varepsilon - 1)}}{O(DJ_{eff}) \cdot (\varepsilon - 1)}\right] \quad (27)$$

and can also be found in, "ONIDS 2002 Review of the 10Gigabit Ethernet Link Model", David Cunningham & Piers Dawe at http://www.avagotech.com/docs/AV02-2485EN

Prior to dawe_1_1001, there were 6 contributions commenting on the need for a reflection noise penalty. Afterwards there were none.

Link Model Background (2 of 2)

Model vs. reality

- Model appears to be pessimistic by ~1-2 dB
  - Reason is not known
    - Could be that receivers are better than we thought (always some transmitter penalty even with test equipment
  - A zero or slightly negative penalty output from the model may be acceptable
- Jitter measurements are inaccurate and not easily corrected by calibration. Big problem.
- Model does not include RJ
  - Assume most RJ is already accounted for as noise in amplitude domain
- The dispersion penalty calculation was meant for multimode lasers, is likely to be inaccurate for single mode lasers

Los Angeles, Oct. 2000 Link Model Update 18

•The 10GbE link model has been a valuable tool for over 10 years.

•10G LR, based on the 10GbE model has been has shipping for ~ 10 years with good results.

•Does anyone believe the definition of 10G LR is broken?

•Recommendation: Continue to use a Reflection Noise factor value of 0.6 in 10GbE based link models.