Considerations and discussion around an optimized link budget for 400GBASE-DR4

- towards TX OMA reduction and PAM4 PMDs alignment -

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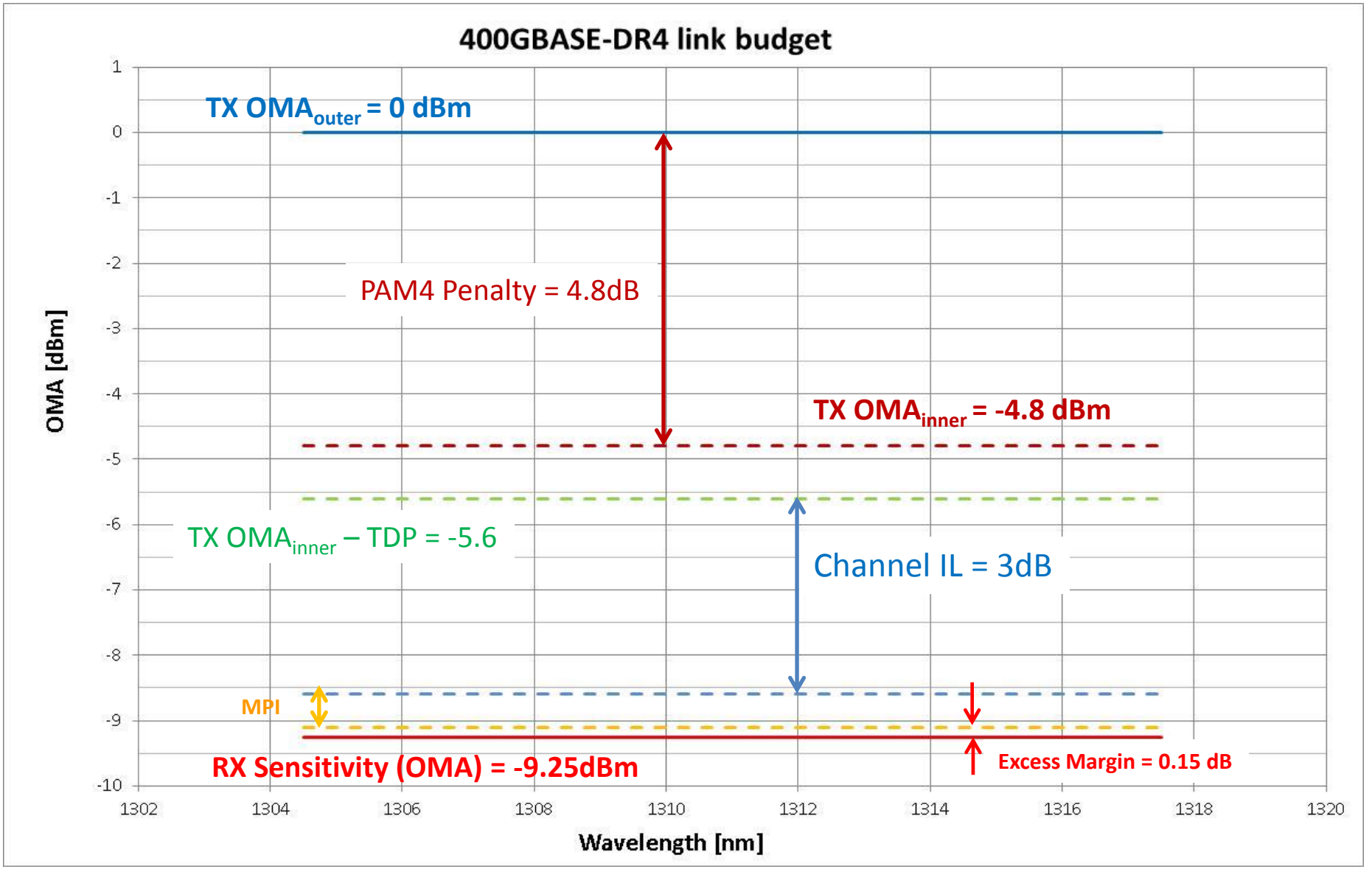
Background

- Pluggable optics power consumption requirements for data center applications are usually the most stringent ones because port density.
- Low power 400G pluggable modules (<3.5W) can enable >12Tb/s troughput on 1RU.
- Laser power will be still a high percentage (estimated 25-28%) of the overall module's power consumption.

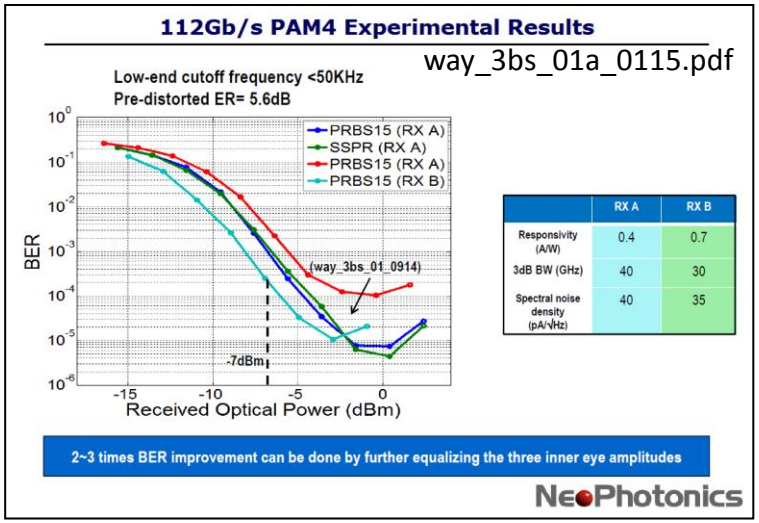
- This contribution suggests a change into 400GBASE-DR4 specification towards an overall module's power consumption reduction.
- Also show how to align 400GBASE-DR4 receiver sensitivity results, link and TX characteristics to other PAM4/802.3bs standard PMDs.

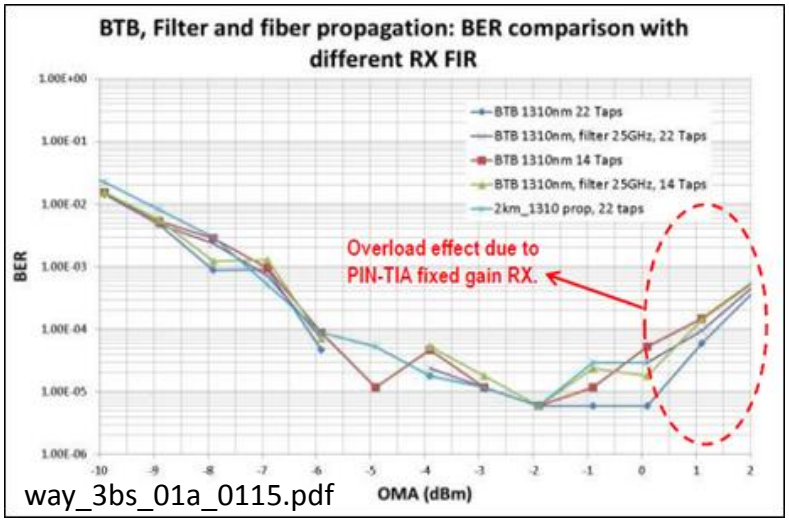
400GBASE-DR4: 802.3bs draft 1.0 link budget.

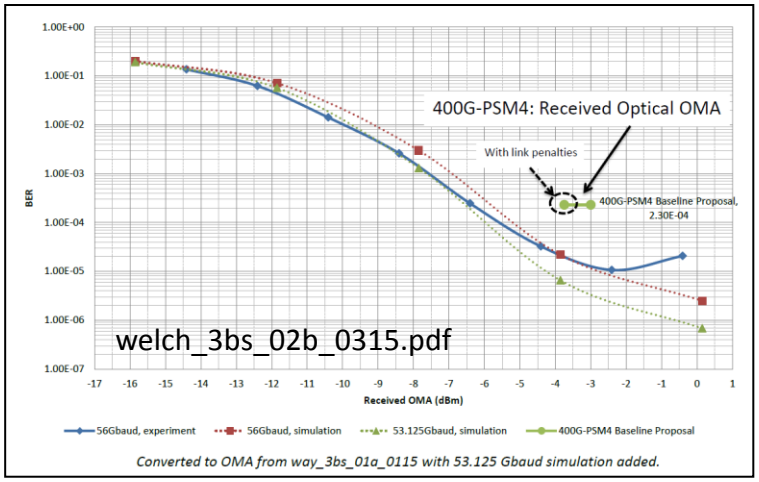


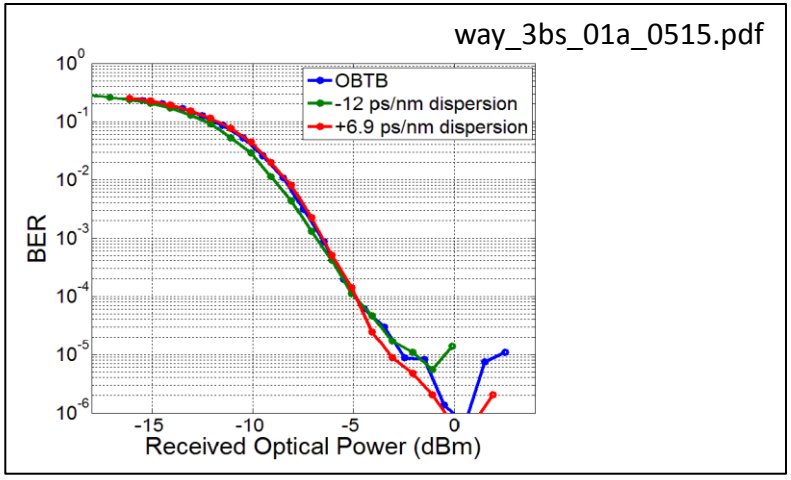
Current 400GBASE-DR4 link budget includes a margin of 0.15dB ([TX OMA$_{innner}$ – TDP] – CH IL - RX Sens) which takes into account MPI penalty (0.5dB) into.

56GBaud RX sensitivity – measurements.





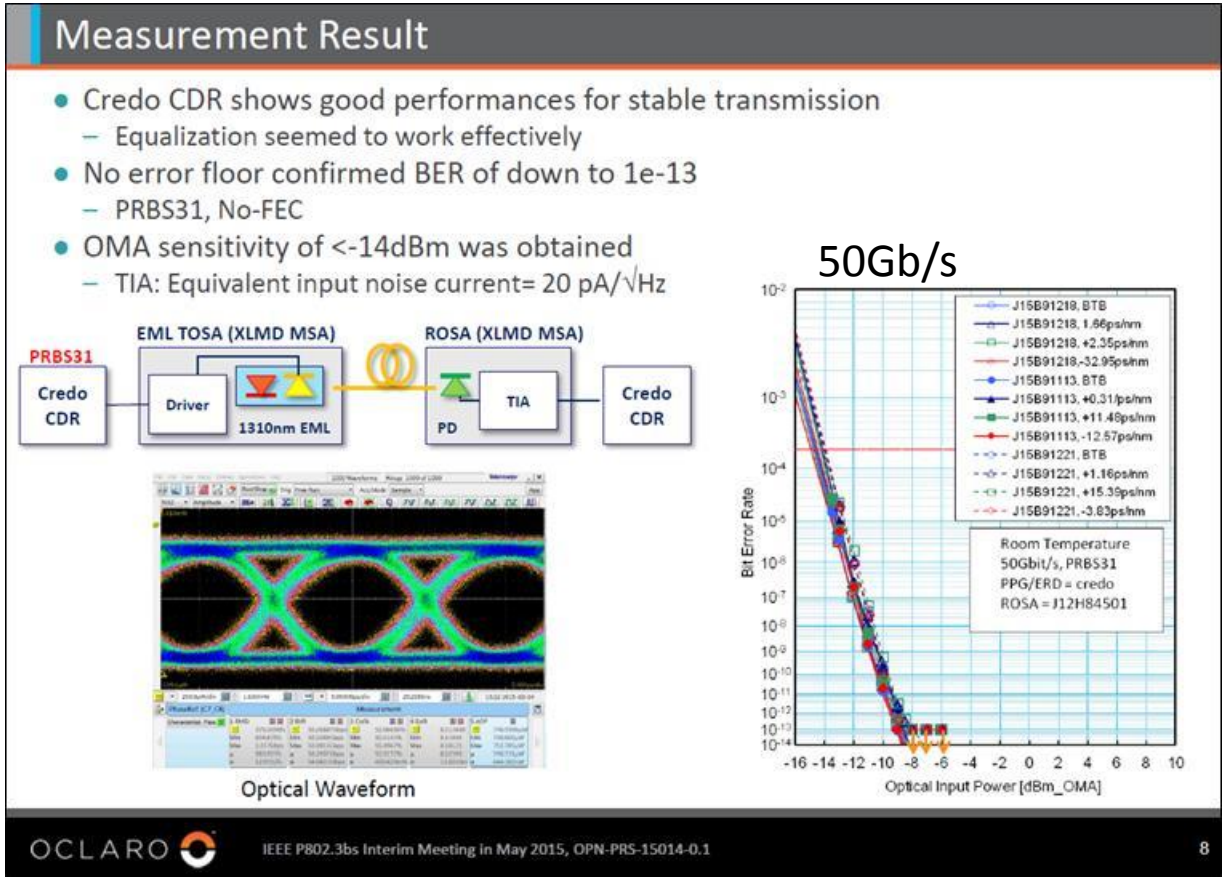




Up to -11.25dBm OMA_{inner} (at 56GBaud) measured sensitivities from different experiments and TX technologies.
> 2dB margin w/respect -9.1dBm OMA sensitivity.
(Note: RX sens = -8.8dBm OMA at TP3 was considered into lewis_3bs_01a_0515, for 400GBASE-FR4 proposal, which included a demux stage of 2dB).

53GBaud RX sensitivity – future improvements?

Expected that Equalizers/TIA/detectors technology will keep improving BW/responsivities.
Currently there >6.5dB delta between the best 26GBaud results (-18dBm) and 56GBaud results, which seems not realistic when 56GBaud (53Gbaud) technology will become mature.

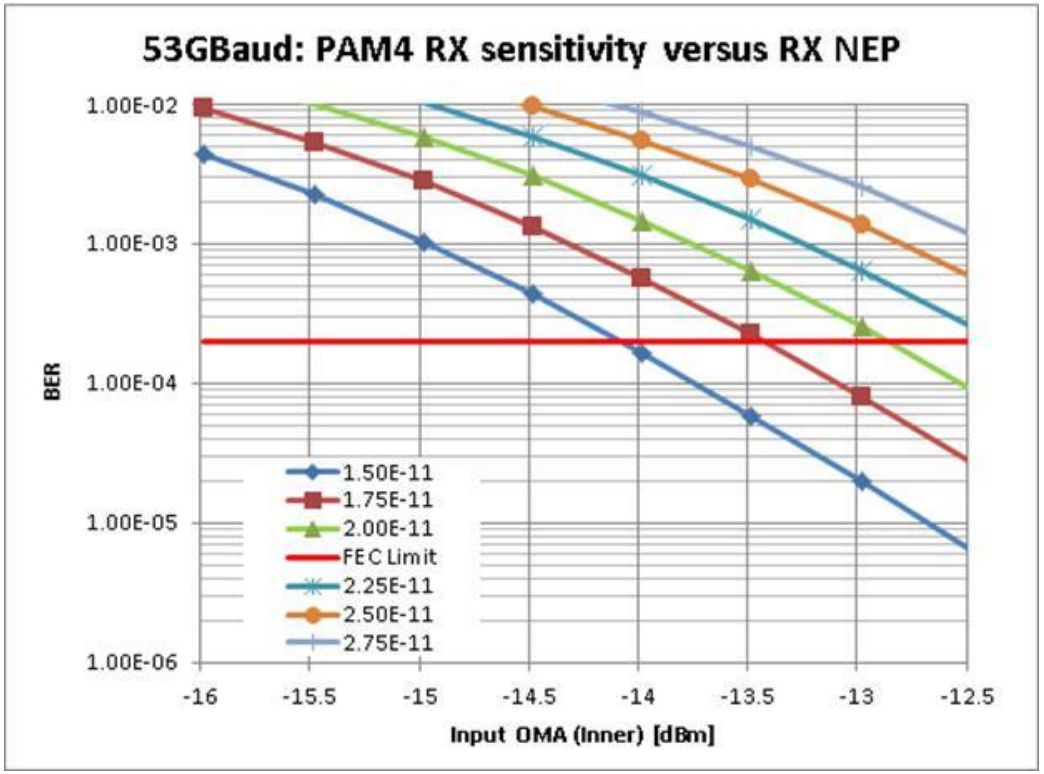


takai_3bs_01b_0515.pdf

Assuming some horizontal eye closure penalty on [01] and [23] eyes, we think -12 to -12.5dBm OMA sensitivity would be possible around 53.2GBaud rate too.

53Gbaud RX sensitivity – simulations.

Currently there's >6.5dB offset between best 26GBaud results (-18dBm) and 56GBaud results, which seems not realistic when 56GBaud (53Gbaud) technology will become mature.



Simulations input conditions of:

Laser RIN = -142 dB/Hz
TX BW = 35 GHz
RX BW = 35 GHz
Responsivity = 0.7 A/W
Residual ISI penalty <0.5dB

Overall (TIA, AGC, ADC) RX NEP (Noise Equivalent Power) swept between 15 to 27.5 pa/√Hz.
20 to 22.5 pa/√Hz is considered feasible at 53GBaud ⇨ RX sensitivity target of around -12.5dBm OMA.
(Note: this value is 1.25dB better then current experiments, but still 5.5 dB worsen than what already experimentally achieved at 26Gbaud).

Proposal

In order to enable lower power consumption towards 400GBASE-DR4 modules, we propose then to:

- Take out any residual margin from current 400GBASE-DR4 budget (0.15dB)
- Incorporate MPI penalty into max TDP of 2.5dB (0.5dB)
- Consider the same PAM4 implementation penalty as for 400GBASE-FR8/LR8 (delta of 0.2dB).
- Reduce TX OMA by 1.5dB;
- Improve RX sensitivity by 1.05dB;

This translates in the following changes into transmit and receive characteristics:

- Table 122-6:
  - TX OMAouter : from 0 to -1.5dBm

  Consequently TX OMAinner will be reduced, but we indeed propose to:
  - remove TX OMAinner from table 122-6 and replace with OMAouter – TDP = -2.3 dBm.
  - Incorporate MPI penalty into max TDP penalty of 2.5dB.
- Table 122-7:
  - RX sensitivity (OMAinner) : from -9.25 to -10.3dBm
- Table 122-8:
  - Add : Allocation for modulation penalties = 5dB.

These changes would still allow to keep a safe optical margin (around 1dB) over current experimental results (looking at simulations > 2dB margins are expected).

Above changes align to the way other PAM4 PMD TX/RX characterisitcs, links budgets and margins (400GBASE-FR8 and LR8) were defined into 123-7, 123-8 and 123-9.

Proposed changes to 400GBASE-DR4 characteristics (1).

Table 122–6—400GBASE-DR4 transmit characteristics

Description	Value		Unit
Signaling rate, each lane (range)	53.125 ± 100 ppm		GBd
Modulation format	PAM4		—
Lane wavelength (range)	1304.5 to 1317.5		nm
Side-mode suppression ratio (SMSR), (min)	30		dB
Average launch power, each lane (max)	4		dBm
Average launch power, each lane[a] (min)	–2.1	**-3.6**	dBm
Outer Optical Modulation Amplitude (OMA_{outer}), each lane (max)	4.2		dBm
Outer Optical Modulation Amplitude (OMA_{outer}), each lane (min)[b]	0	**-1.5**	dBm
~~Inner Optical Modulation Amplitude (OMA_{inner}), each lane (min)[b]~~	~~–4.8~~		~~dBm~~
~~Launch power in OMA_{inner} minus TDP, each lane (min)~~	~~–5.6~~	**-2.3**	dBm
Transmitter and dispersion penalty (TDP), each lane (max)	2.5		dB
Average launch power of OFF transmitter, each lane (max)	–30		dBm
Extinction ratio, each lane (min)	5		dB
$RIN_{xx}OMA$ (max)	–142		dB/Hz
Optical return loss tolerance (max)	TBD		dB
Transmitter reflectance[c] (max)	–20		dB
Transmitter eye mask definition	TBD		

[a]Average launch power, each lane (min) is informative and not the principal indicator of signal strength. A transmitter with launch power below this value cannot be compliant; however, a value above this does not ensure compliance.
[b]Even if the TDP < 0.8 dB, the OMA_{outer} (min) and OMA_{inner}(min) must exceed these values.
[c]Transmitter reflectance is defined looking into the transmitter.

Relax these too?

OMAouter proposed relaxation

Remove OMAinner parameter

Launch power in OMA**outer** minus TDP, each lane (min)

MPI included into max TDP

This align with 400GBASE-FR8/LR8 TX/RX characteristics of Table 123-7.
Proposed changes to transmitter characteristics are in red.

Proposed changes to 400GBASE-DR4 characteristics.

Table 122–7—400GBASE-DR4 receive characteristics

Description	Value	Unit
Signaling rate, each lane (range)	53.125 ± 100 ppm	GBd
Modulation format	PAM4	—
Lane wavelengths (range)	1304.5 to 1317.5	nm
Damage threshold[a] (min)	6.5	dBm
Average receive power, each lane (max)	4	dBm
Average receive power, each lane[b] (min)	–5.1 **-6.15**	dBm
Receive power, each lane (OMA_{outer}) (max)	4.2	dBm
Receiver reflectance (max)	–26	dB
Receiver sensitivity (OMA_{inner}), each lane[c] (max)	–9.25 **-10.3**	dBm
Receiver 3 dB electrical upper cutoff frequency, each lane (max)	TBD	GHz
Stressed receiver sensitivity (OMA_{inner}), each lane[d] (max)	TBD	dBm
Conditions of stressed receiver sensitivity test:		
Condition 1[e]	TBD	
Condition 2[e]	TBD	

[a]The receiver shall be able to tolerate, without damage, continuous exposure to an optical input signal having this average power level. The receiver does not have to operate correctly at this input power.
[b]Average receive power, each lane (min) is informative and not the principal indicator of signal strength. A received power below this value cannot be compliant; however, a value above this does not ensure compliance.
[c]Receiver sensitivity (OMA_{inner}), each lane (max) is informative.
[d]Measured with conformance test signal at TP3 (see 122.8.10) for the BER specified in 122.1.1.
[e]Condition 1 and condition 2 are test conditions for measuring stressed receiver sensitivity. They are not characteristics of the receiver.

Relax these too?

Should provide some benefit too (less distortions).

Receiver sensitivity (OMA_{inner}) proposed change

Proposed changes to receive and link budget characteristics are in red.

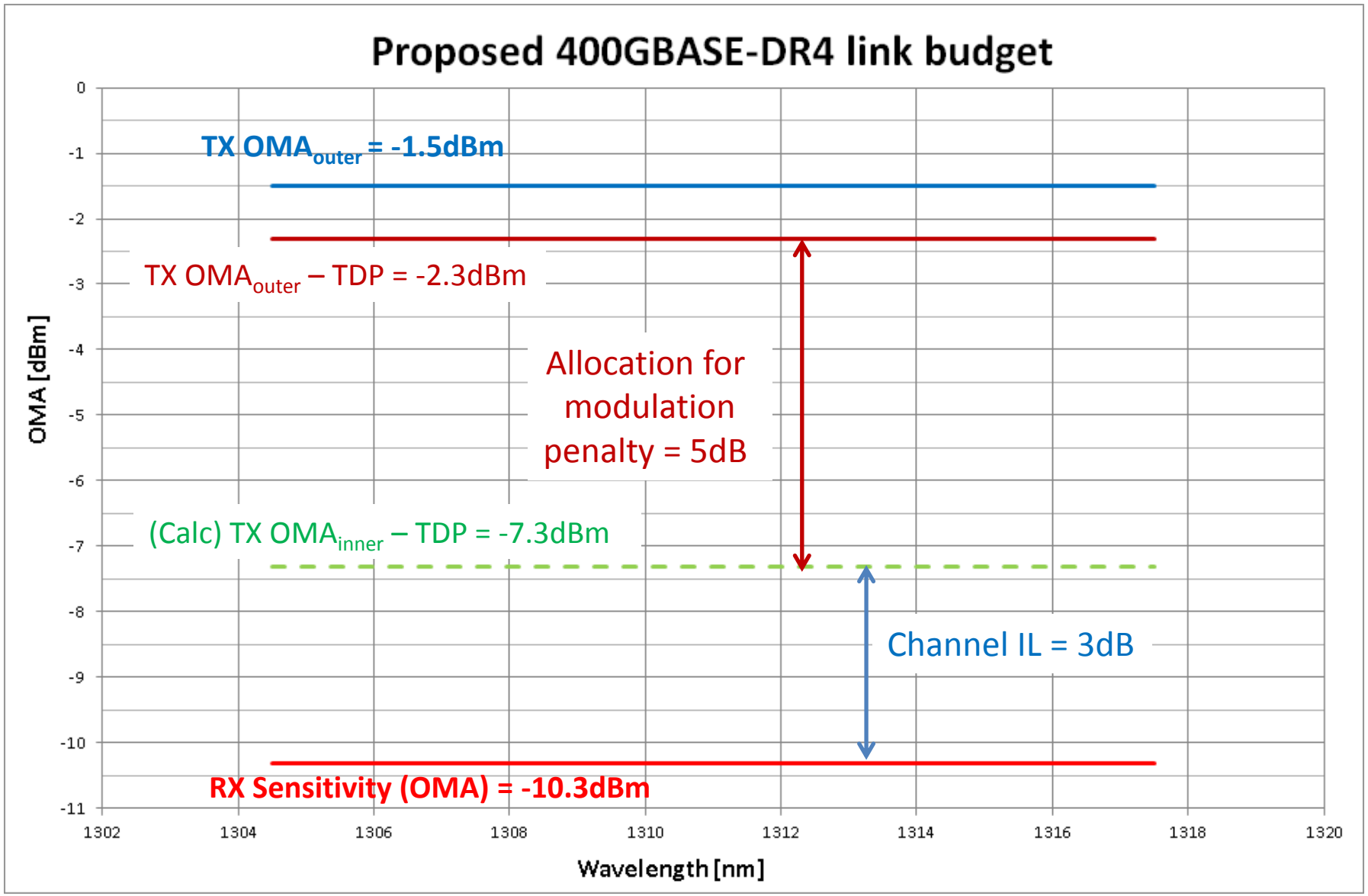
Table 122–8—400GBASE-DR4 illustrative link power budget

Parameter	Value	Unit
Power budget (for max TDP)	TBD	dB
Operating distance	500	m
Channel insertion loss[a]	3	dB
Maximum discrete reflectance	–35	dB
Allocation for penalties[b] (for max TDP)	3 **2.5**	dB
Additional insertion loss allowed	0	dB

Include MPI penalty into allocation into max TDP penalties

Add a row: Allocation for modulation penalties of 5dB

Proposed 400GBASE-DR4 link budget.



Conclusion

- An opportunity to shift the 400GBASE-DR4 link budget RX sensitivity and TX OMA is given.
  - **This assumes expected 400GBASE-DR4 receiver to behave better than current experimental results, so target more margins.**
  - **This actually seems more than reasonable to us by looking at current sensitivity delta w/respect others PAM4/802.3bs standard PMDs receivers.**
- The improvement in TX yield and module's power consumption will benefit future developments of 400GBASE-DR4 in small form factor.
- We also think should be worthwhile to align the 400GBASE-DR4 TX and link characteristics of tables 122-6 and 122-8 to the 400GBASE-FR8/LR8 ones (tables 123-7 and 123-9).

THANK YOU

Back-up slides

Discussion

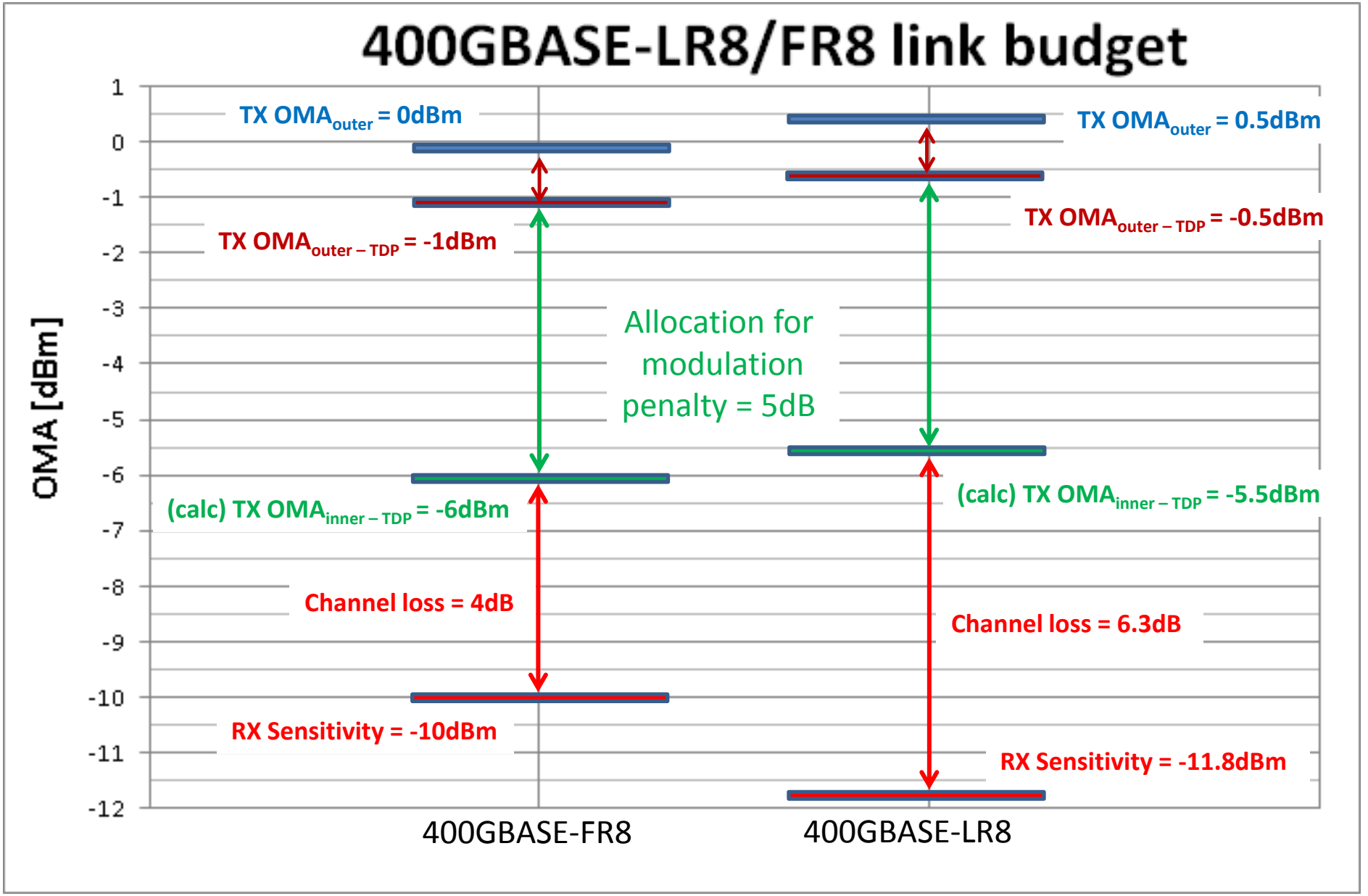
- During the March 2015 P802.3bs TF meeting 50G PAM-4 RX Sens. (inner eye OMA) data was presented
  - Finisar RX Sens. = ~-13.5dBm (BER = 2e-4)

    http://www.ieee802.org/3/bs/public/15_03/cole_3bs_02_0315.pdf#page=24
  - Huawei RX Sens. = ~-18dBm (BER = 2e-4)

    http://www.ieee802.org/3/bs/public/15_03/stassar_3bs_01a_0315.pdf#page=5
- Since the meeting, below deltas were identified:

Parameter	Finisar	Huawei
Noise Current	16.5pA/√HZ	15pA/√HZ
PD responsivity	0.5A/W	0.85A/W
Pattern	SSPR	PRBS15
GBaud	28	25.8

- With 0.8A/W PD responsivity, Finisar has since measured RX Sens. = ~-17dBm (BER = 2e-4)


400GBASE-LR8/FR8 link budget
OMA [dBm]
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
TX OMA$_{outer}$ = 0dBm
TX OMA$_{outer-TDP}$ = -1dBm
Allocation for modulation penalty = 5dB
(calc) TX OMA$_{inner-TDP}$ = -6dBm
Channel loss = 4dB
RX Sensitivity = -10dBm
TX OMA$_{outer}$ = 0.5dBm
TX OMA$_{outer-TDP}$ = -0.5dBm
(calc) TX OMA$_{inner-TDP}$ = -5.5dBm
Channel loss = 6.3dB
RX Sensitivity = -11.8dBm
400GBASE-FR8
400GBASE-LR8

Draft 1.0 - 400GBASE-FR8/LR8 characteristics

Table 123–7—400GBASE-FR8 and 400GBASE-LR8 transmit characteristics

Description	400GBASE-FR8	400GBASE-LR8	Unit
Signaling rate, each lane (range)	26.5625 ± 100 ppm		GBd
Modulation format	PAM4		—
Lane wavelengths (range)	1272.55 to 1274.54 1276.89 to 1278.89 1281.25 to 1283.27 1285.65 to 1287.68 1294.53 to 1296.59 1299.02 to 1301.09 1303.54 to 1305.63 1308.09 to 1310.19		nm
Side-mode suppression ratio (SMSR), (min)	30		dB
Total average launch power (max)	13.2		dBm
Average launch power, each lane (max)	4.2		dBm
Average launch power, each lane[a] (min)	-3	-2.5	dBm
Outer Optical Modulation Amplitude (OMA_{outer}), each lane (max)	5.5	5.7	dBm
Outer Optical Modulation Amplitude (OMA_{outer}), each lane (min)[b]	0	0.5	dBm
Difference in launch power between any two lanes (OMA) (max)	TBD	TBD	dB
Launch power in OMA_{outer} minus TDP, each lane (min)	–1	–0.5	dBm
Transmitter and dispersion penalty (TDP), each lane (max)	2	2.2	dB
Average launch power of OFF transmitter, each lane (max)	–30		dBm
Extinction ratio (min)	4.5		dB
$RIN_{xx}OMA$ (max)	TBD		dB/Hz
Optical return loss tolerance (max)	TBD		dB
Transmitter reflectance[c] (max)	TBD		dB
Transmitter eye mask definition	TBD		

[a]Average launch power, each lane (min) is informative and not the principal indicator of signal strength. A transmitter with launch power below this value cannot be compliant; however, a value above this does not ensure compliance.
[b]Even if the TDP < 1 dB, the OMA_{outer} (min) must exceed this value.
[c]Transmitter reflectance is defined looking into the transmitter.

Table 123–8—400GBASE-FR8 and 400GBASE-LR8 receive characteristics

Description	400GBASE-FR8	400GBASE-LR8	Unit
Signaling rate, each lane (range)	26.5625 ± 100 ppm		GBd
Modulation format	PAM4		—
Lane wavelengths (range)	1272.55 to 1274.54 1276.89 to 1278.89 1281.25 to 1283.27 1285.65 to 1287.68 1294.53 to 1296.59 1299.02 to 1301.09 1303.54 to 1305.63 1308.09 to 1310.19		nm
Damage threshold[a]	5.2		dBm
Average receive power, each lane (max)	4.2		dBm
Average receive power, each lane[b] (min)	-7	-8.8	dBm
Receive power, each lane (OMA_{outer}) (max)	5.5	5.7	dBm
Difference in receive power between any two lanes (OMA_{inner}) (max)	TBD	TBD	dB
Receiver reflectance (max)	TBD		dB
Receiver sensitivity (OMA_{inner}), each lane[c] (max)	–10	–11.8	dBm
Receiver 3 dB electrical upper cutoff frequency, each lane (max)	21		GHz
Stressed receiver sensitivity (OMA_{inner}), each lane[d] (max)	TBD	TBD	dBm
Conditions of stressed receiver sensitivity test			
Condition 1[e]	TBD	TBD	
Condition 2[e]	TBD	TBD	

Table 123–9—400GBASE-FR8 and 400GBASE-LR8 illustrative link power budgets

Parameter	400GBASE-FR8	400GBASE-LR8	Unit
Power budget (for maximum TDP)	11	13.5	dB
Operating distance	2	10	km
Channel insertion loss	4[a]	6.3	dB
Maximum discrete reflectance	TBD	TBD	dB
Allocation for penalties[b] (for maximum TDP)	2	2.2	dB
Allocation for modulation penalties[b]	5	5	dB
Additional insertion loss allowed,	0	0	dB

[a]The channel insertion loss is calculated using TBD plus an allocation for connection and splice loss given in 123.11.2.1.
[b]Link penalties are used for link budget calculations. They are not requirements and are not meant to be tested.

Optical Margin

Description (Inner Eye)	400GBASE-FR8	400GBASE-LR8	Unit
Receiver Sensitivity (OMA), each lane, pre-DeMux (max)	-10.0	-11.8	dBm
DeMux Loss	3.0	3.0	dB
Cross-talk penalty	0.3	0.3	dB
Receiver Sensitivity (OMA), each lane, post-DeMux (max)	-13.3	-15.1	dBm
Receiver Sensitivity (OMA) single lane (typical measured)	-17	-17	dBm
Optical Margin	3.7	1.9	dB