400GBASE-DR4 PMD
Considerations for TX OMA reduction

Marco Mazzini
- Cisco -

Background

Starting from previous set of slides and presentation given at latest IEEE meeting, we've been investigating the possibility to relax the TX OMA $_{outer}$ and tight RX sensitivity requirements.

Path for lowering TX power (TX OMA)

Different considerations for TX OMA reduction.

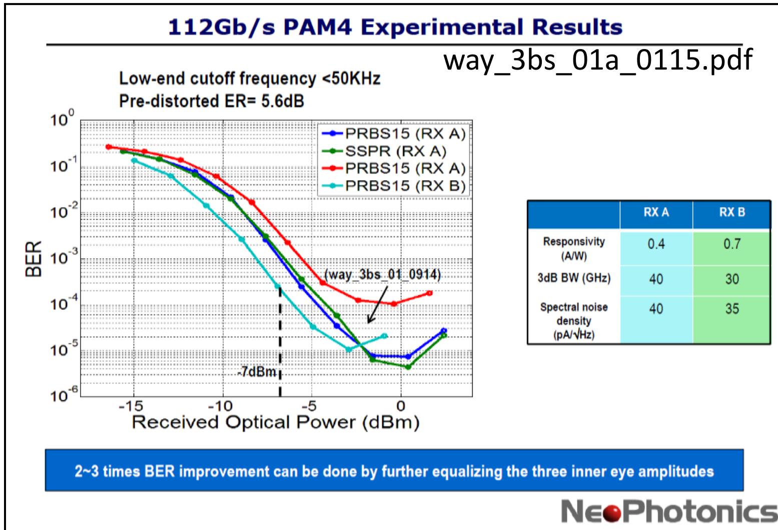
1. Updated budget presented into slide 9 already allows 0.6dB TX OMA relaxation, keeping same Draft 1.0 RX sensitivity (-9.25dBm OMA_{inner}).
   - MPI penalty relaxation (from 0.5 to 0.15dB)
   - PAM4 0.1dB implementation penalties relaxation (from 4.8 to 4.7dB).
   - Excess margin removal (0.15dB).

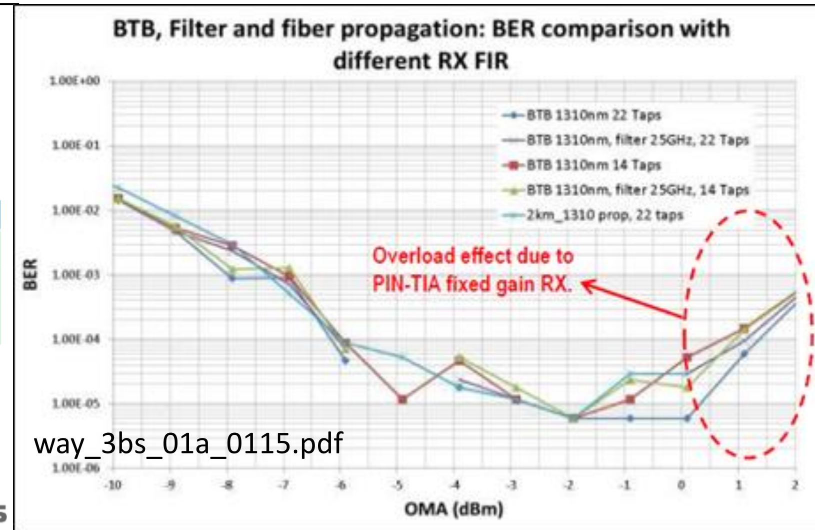
2. Our updated experimental results will show that:
   - Different RX equalizers already allow good sensitivity margins.

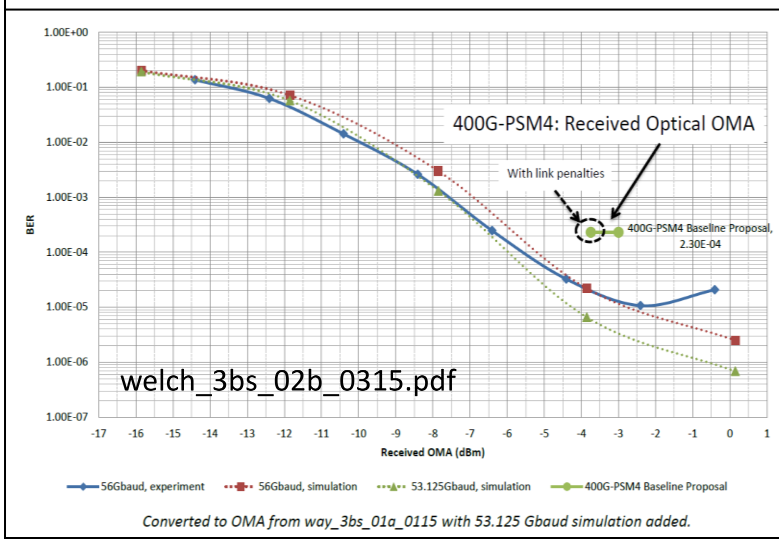
3. Considering RX technology evolutions, we kept included same simulation slide given into latest IEEE showing:
   - New generation of linear TIAs (lower NEP) will allow to improve even more RX sensitivity margins and noise floor.

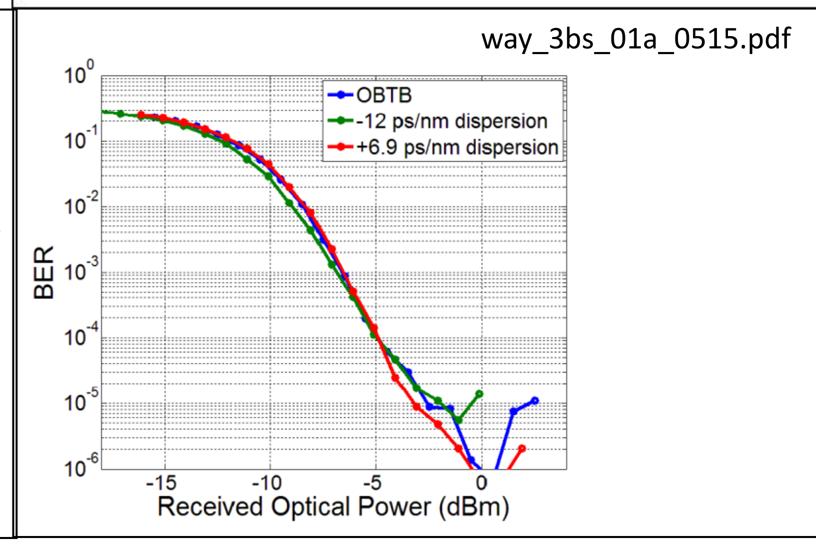
56GBaud RX sensitivity – some previous results.

-6.45dBm OMA (-11.15 dBm RX Sens inner Pre-post TX/RX FFE)







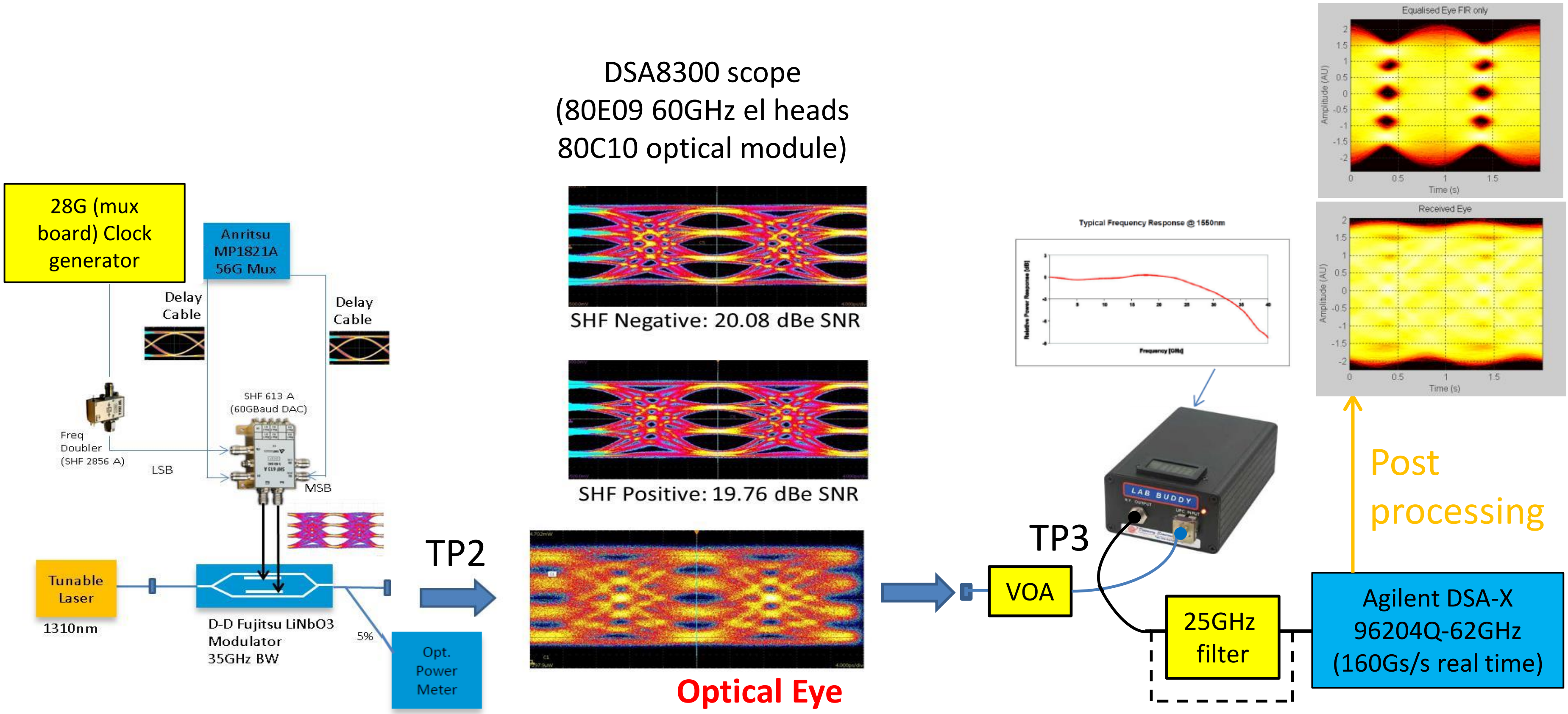


Considered 0.5dB OMA improvement calculated between 56 to 53.125GBaud.

No penalties due to lower BW and fiber propagation (2kms).

Up to -11.15dBm OMA_{inner} at 56GBaud (≈-11.65 at 53Gbaud) measured sensitivities from different experiments and TX technologies (> 2.5dB margin w/respect Draft1.1 - RX OMA sensitivity of -9.1dBm).

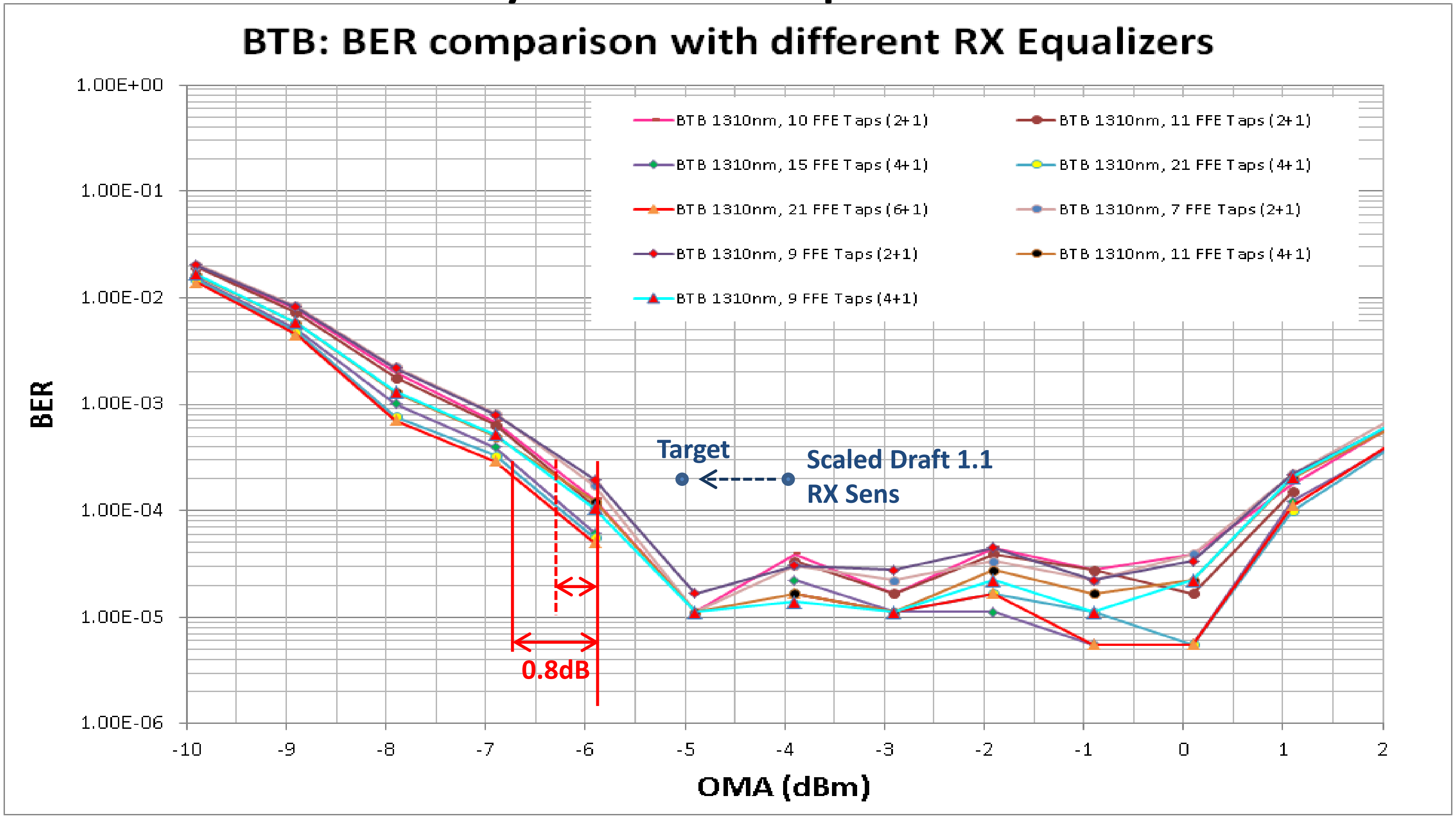
PAM 4 TX/RX : set-up with LiNb03 modulator.



- SHF613A and 2856A provide a good electrical signal and allow dual-drive modulator to generate a 56GBaud signal.
- Clock generator was improved with respect previous tests (but limited to fixed 56GBaud).
- DSC-R409 (linear InGaAs receiver) has good frequency response but expect higher NEP (>30pa/√Hz, no AGC) w/respect new generation of linear TIAs for 53GBaud application.

We expect experimental results with discrete components to be (at this stage) worsen than any integrated implementation because the amount of optical/electrical connections in the set-up and RX limitations.

56GBaud sensitivity vs FFE equalizers



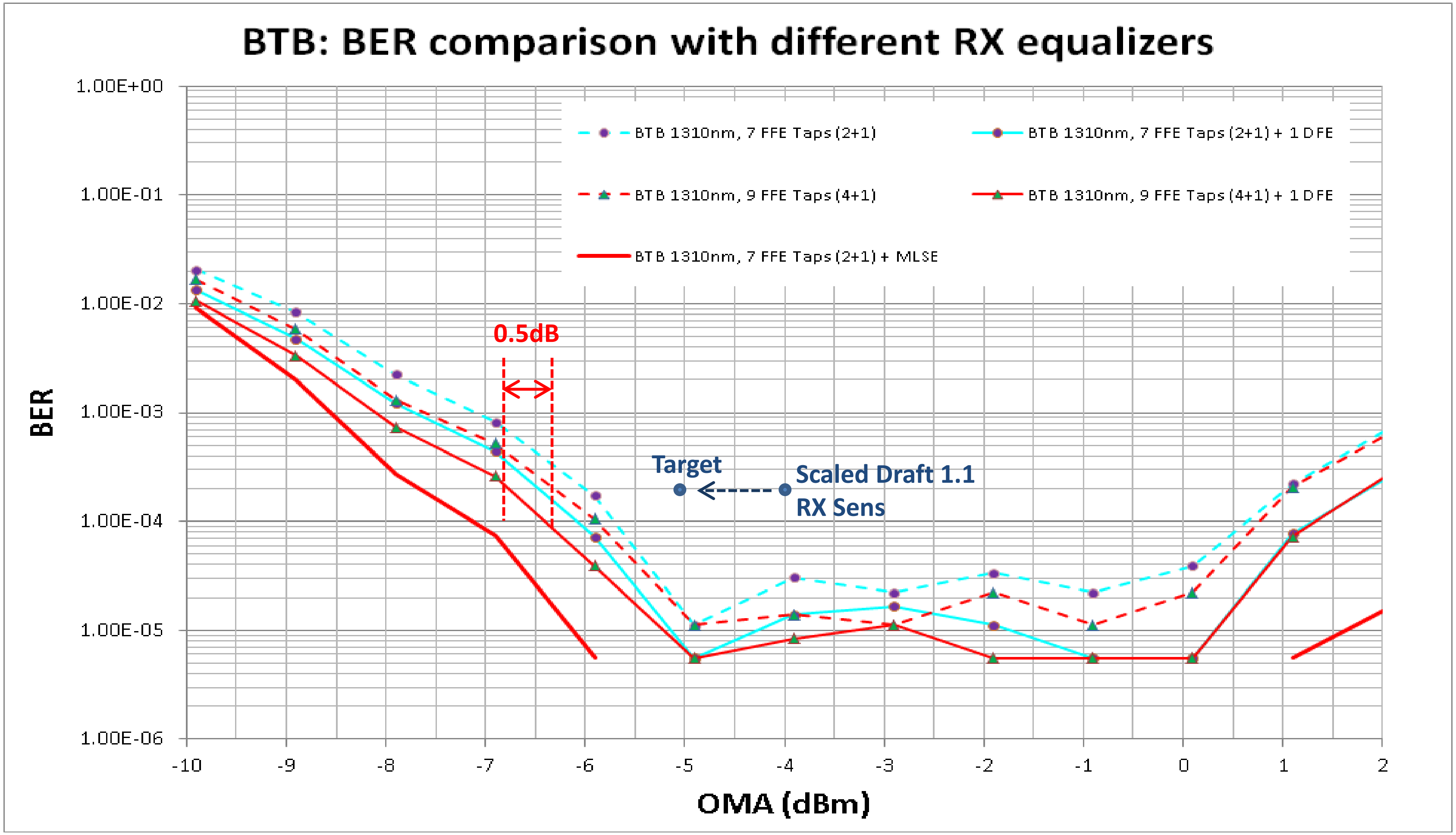
There's a good «flat» range between 0 to -5dBm range (@53G, -0.5 to -6dBm).

Observed around 0.4dB penalty between 7 (2+1) and 9 (4+1) FFE (T/2) taps equalization.

Other further 0.4dB improvement are achieved with more taps (15/21 T/2 spaced).

- 7 taps = -5.9 dBm RX sensitivity outer (-10.6 RX sensitivity OMA inner).
- 9 taps = -6.3 dBm outer (-11 dBm)
- 21 taps = -6.7 dBm outer (-11.4 dBm) -> ≈ -7.2 dBm (-11.9 dBm inner) RX sensitivity @53GBaud.

56GBaud sensitivity with different equalizer types



Observed same (≈0.5 dB) improvement including 1 DFE tap added to 7 and 9 FFE equalizers.

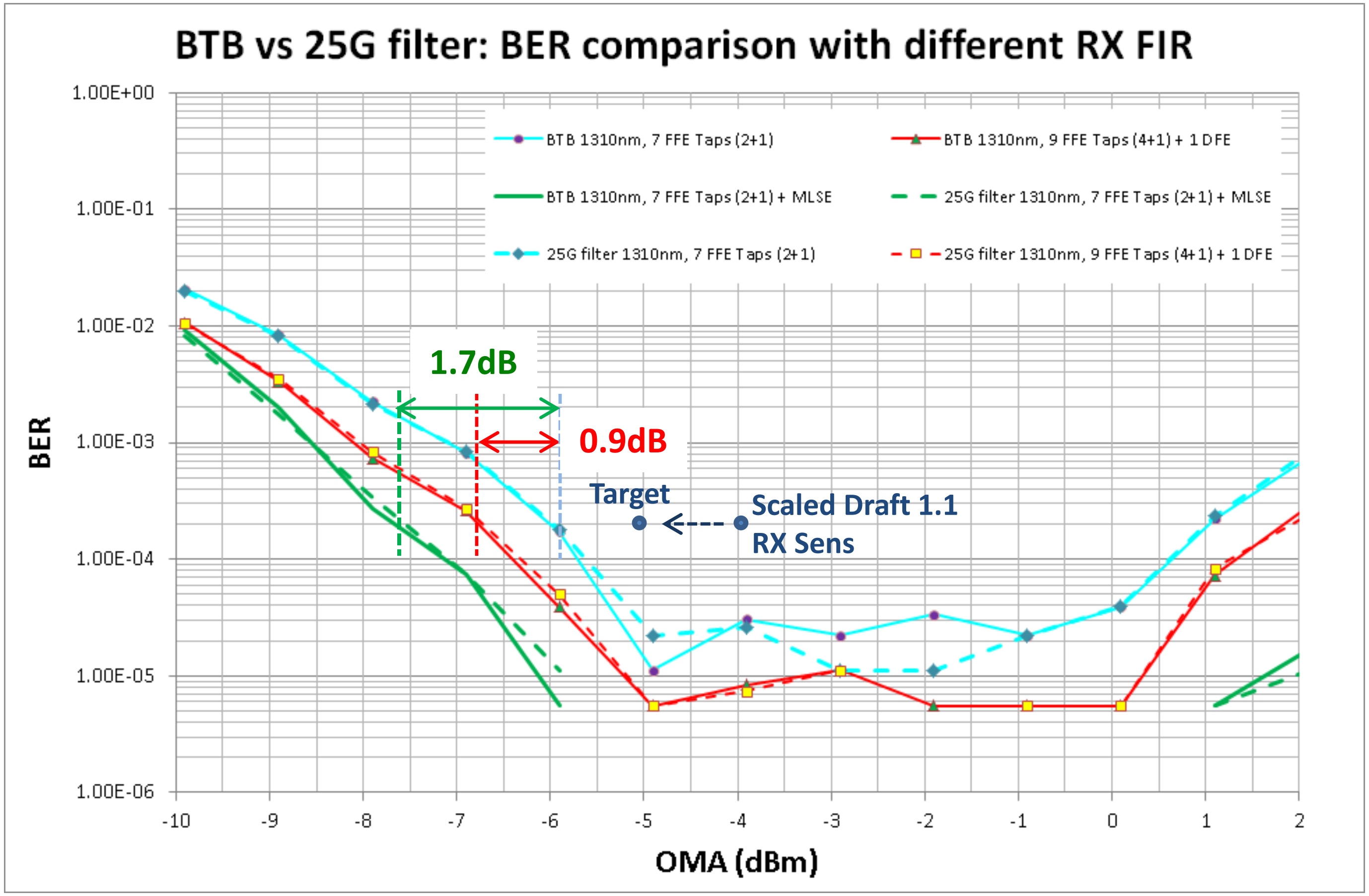
7 FFE + 1 DFE = -6.5 dBm RX sensitivity outer (-11.2 RX sensitivity OMA inner).

9 FFE + 1 DFE = -6.8 dBm outer (-11.5 dBm)

MLSE (3 bits) = -7.6 dBm outer (-12.3 dBm) -> ≈ -8.2 dBm (-12.8 dBm inner) RX sensitivity @53GBaud

Note we're not saying that MLSE has to be implemented, just exploring current sensitivity limits.

25GHz (RX filter) – results summary



25GHz BW filter used, to simulate more restricted BW components.

There's almost no penalty (0.1dB).

Measured 56Gbaud RX sensitivity, OMA

Condition	7 FFE	9 FFE	21 FFE	7 FFE / 1 DFE	9 FFE / 1 DFE	MLSE
BTB	-10.6	-11	-11.5	-11.2	-11.5	-12.3
25G Filter	-10.5				-11.4	-12.2

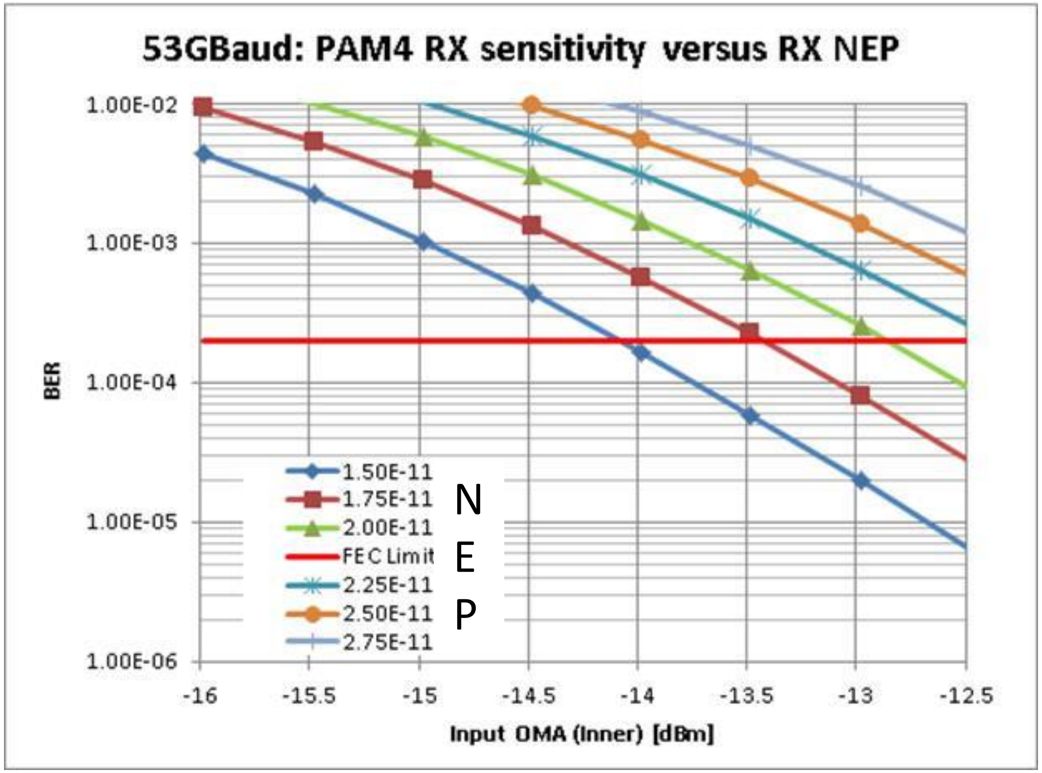
Calculated 53.125GBaud RX sensititivity, OMA

Condition	7 FFE	9 FFE	21 FFE	7 FFE / 1 DFE	9 FFE / 1 DFE	MLSE
BTB	-11.1	-11.5	-12	-11.7	-12	-12.8
25G Filter	-11				-11.9	-12.7

From resultsm -13dBm (-8.3dBm outer) is achievable (4dB margin w/respect current sensitivity specs).

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
Equivalent 7 FFE taps (T/2 spaced)

Overall (TIA, AGC, ADC) RX NEP (Noise Equivalent Power) swept between 15 to 27.5 pa/√Hz.

NEP between 20-22.5 pa/√Hz is considered feasible at 53GBaud by us ⇨ RX sensitivity target of around -12.75dBm OMA (Note: this value is ≈1.5dB better then current (7 taps FFE) experiments results (still 5.5 dB worsen than what already experimentally shown at 26Gbaud).

Conclusions

We think there's room to enable lower TX power and get to TX OMA reduction (target -1.4 dBm) by tightening RX sensitivity.

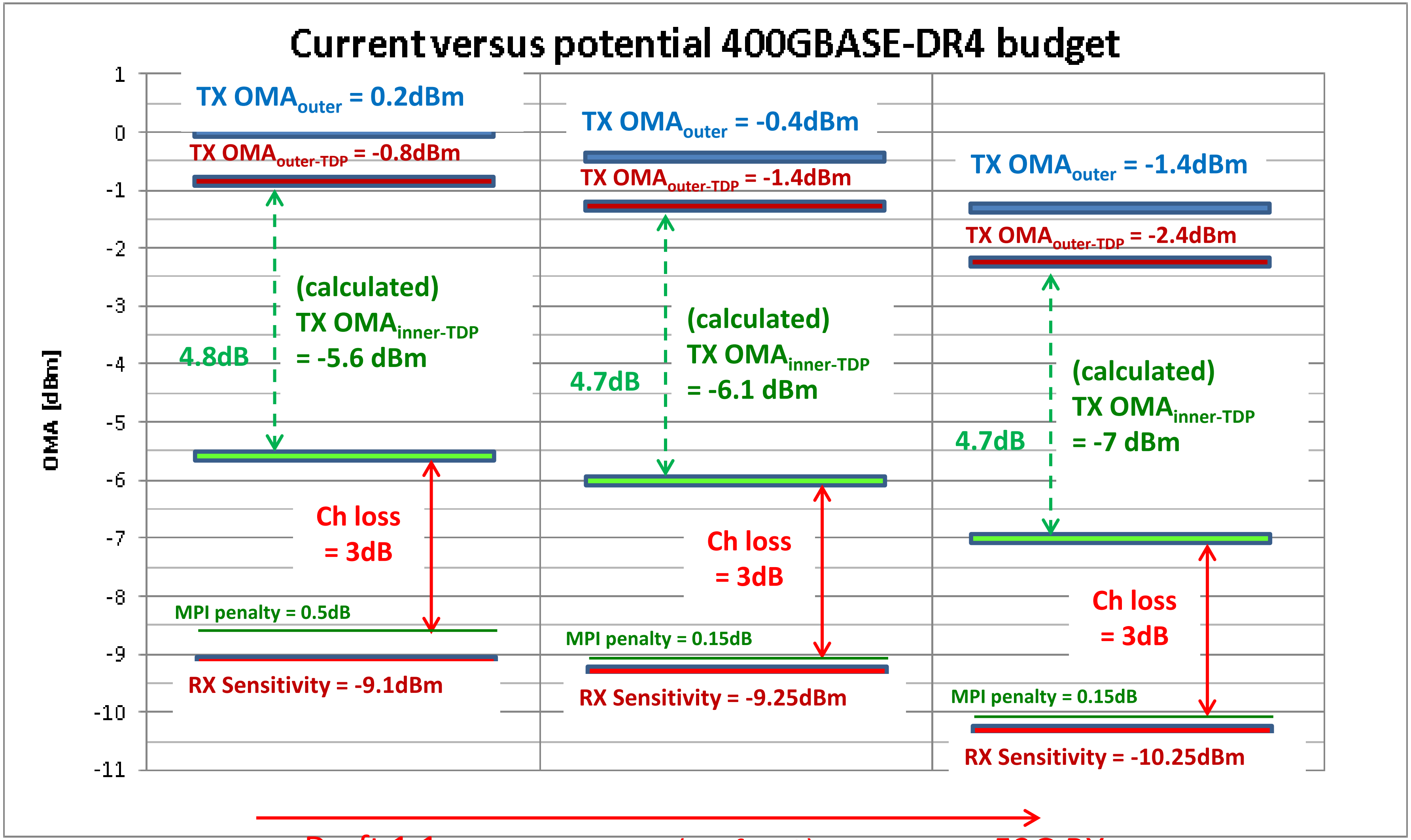
- The intention is still allow to keep a safe optical margin for development (2.5dB, considering 1dB ageing and 1dB voltage/temperature corners).

Calculated (from 56G experiment) 53.125GBaud RX sensititivity, OMA

	Condition	7 FFE	9 FFE	21 FFE	7 FFE / 1 DFE	9 FFE / 1 DFE	MLSE	Calc 7 taps NEP 20-22.5 pa√Hz
	BTB	-11.1	-11.5	-12	-11.7	-12	-12.8	-12.75
	25G Filter	-11				-11.9	-12.7	
Margins (dB)	Draft 1.1 (-9.1 dBm)	2	2.4	2.9	2.6	2.9	3.7	3.65
	Target (-10.25 dBm)	0.85	1.25	1.75	1.45	1.75	2.55	2.5

- Looking at simulations results and test results, this can be targeted considering to reduce OMA RX sensitivity to -10.25 dBm.
- We expect to see components becoming available in the near future, and plan to run further experiments.
- We are also looking forward for further contributions confirming our findings.

Potential path for 400GBASE-DR4 budget.



Draft 1.1 specs

PAM4 (Draft 1.2) harmonization

53G RX technology improvement

THANK YOU

Back-up slides

Discussion

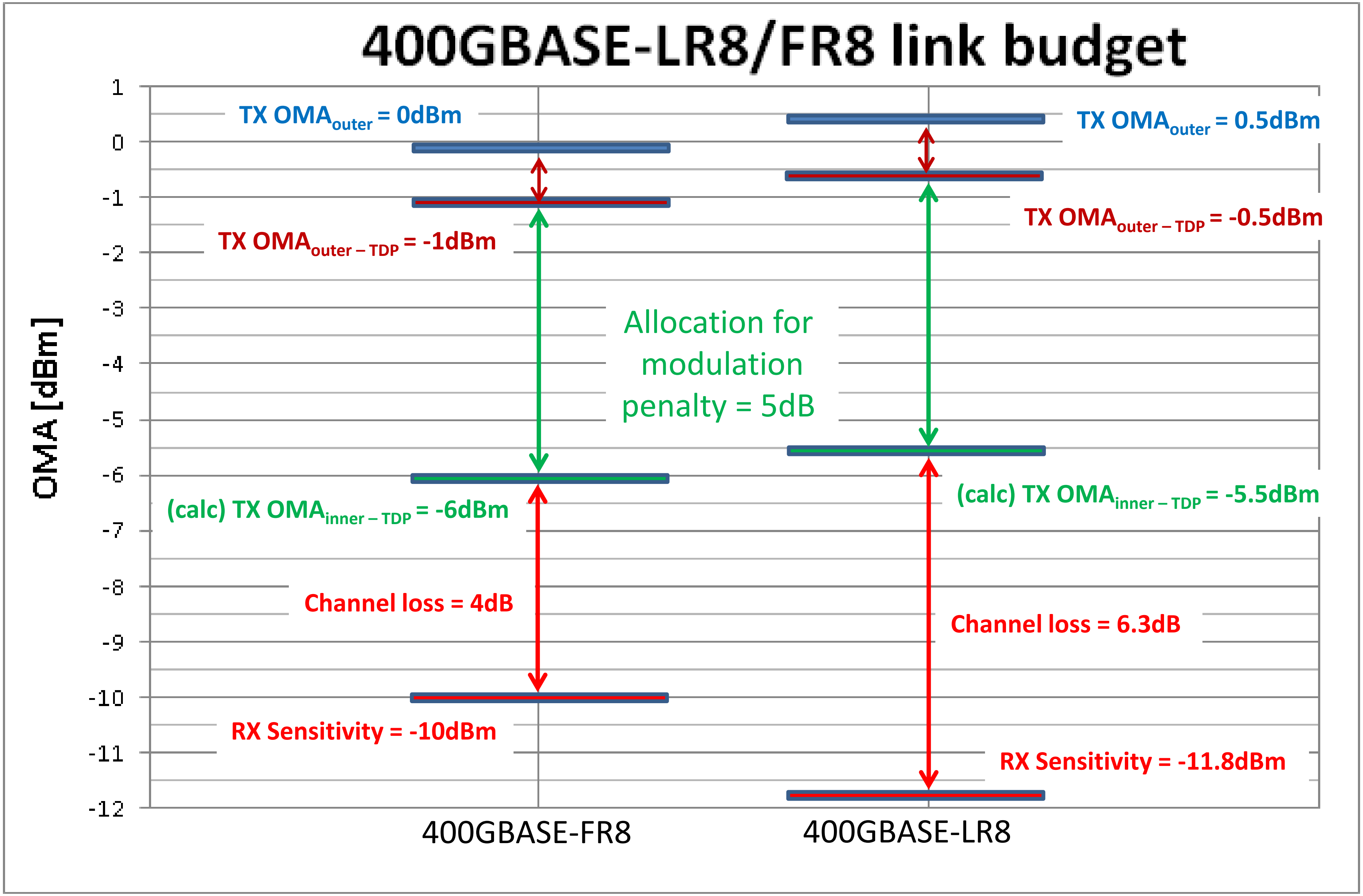
- During the March 2015 P802.3bs TF meeting 50G PAM-4 RX Sens. (inner eye OMA) data was presented
  - Finisar RX Sens. = ~-13.5dBm (BER = 2e-4)

    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$_{outer}$ = 0.5dBm
TX OMA$_{outer-TDP}$ = -1dBm
TX OMA$_{outer-TDP}$ = -0.5dBm
Allocation for modulation penalty = 5dB
(calc) TX OMA$_{inner-TDP}$ = -6dBm
(calc) TX OMA$_{inner-TDP}$ = -5.5dBm
Channel loss = 4dB
Channel loss = 6.3dB
RX Sensitivity = -10dBm
RX Sensitivity = -11.8dBm
400GBASE-FR8
400GBASE-LR8

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

One option for changes to 400GBASE-DR4 characteristics.

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)	−1.9 **-3.4**	dBm
Outer Optical Modulation Amplitude (OMA_{outer}), each lane (max)	4.2	dBm
Outer Optical Modulation Amplitude (OMA_{outer}), each lane (min)[b]	0.2 **-1.3**	dBm
Launch power in OMA_{outer} minus TDP, each lane (min)	−0.8 **-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 **-26**	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) and OMA_{inner}(min) must exceed these values.
[c]Transmitter reflectance is defined looking into the transmitter.

We should actually relax these too (link is broken because distortions, maybe AGC would help).

Our OMAouter target

Our OMAouter minus TDP, each lane (min) target !

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], each lane (min)	6.5	dBm
Average receive power, each lane (max)	4	dBm
Average receive power, each lane[b] (min)	−4.9 **-6.4**	dBm
Receive power, each lane (OMA_{outer}) (max)	4.2	dBm
Receiver reflectance (max)	−26	dB
Receiver sensitivity (OMA_{inner}), each lane[c] (max)	−9.1 **-10.25**	dBm
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.

We should actually relax these too (link is broken because distortions, maybe AGC would help).

Receiver sensitivity (OMA_{inner}) proposed change
[= -5.55dBm OMA_{outer}]

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)	6	dB
Operating distance	500	m
Channel insertion loss[a]	3 **2.75**	dB
Maximum discrete reflectance	−35	dB
Allocation for penalties[b] (for max TDP)	3	dB
Additional insertion loss allowed	0	dB

[a]The channel insertion loss is calculated using the maximum distance specified in Table 122–5 and cabled optical fiber attenuation of 0.5 dB/km at 1304.5 nm plus an allocation for connection and splice loss given in 122.11.2.1.
[b]Link penalties are used for link budget calculations. They are not requirements and are not meant to be tested.

Include MPI penalty into allocation into max TDP penalties