Baseline proposals for 200G/L PMD 500 m and 2 km objectives

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FEC Definitions

- **FECo**: Optical link runs with RS(544,514) FEC protection.

- **FECi**: Optical link runs with RS(544,514) FEC protection operating as an outer code, supplemented by Hamming(128,120) FEC protection operating as an inner code.

Overview

Revisions relative to Welch_3dj_03_2309 & Welch_3dj_04_2309:

- Integrates single wavelength and multi wavelength proposals (up to 2km) into a single presentation.

- Updates to Reference EQ depth: Revised to FFE11
  - Previously indicated as TBD

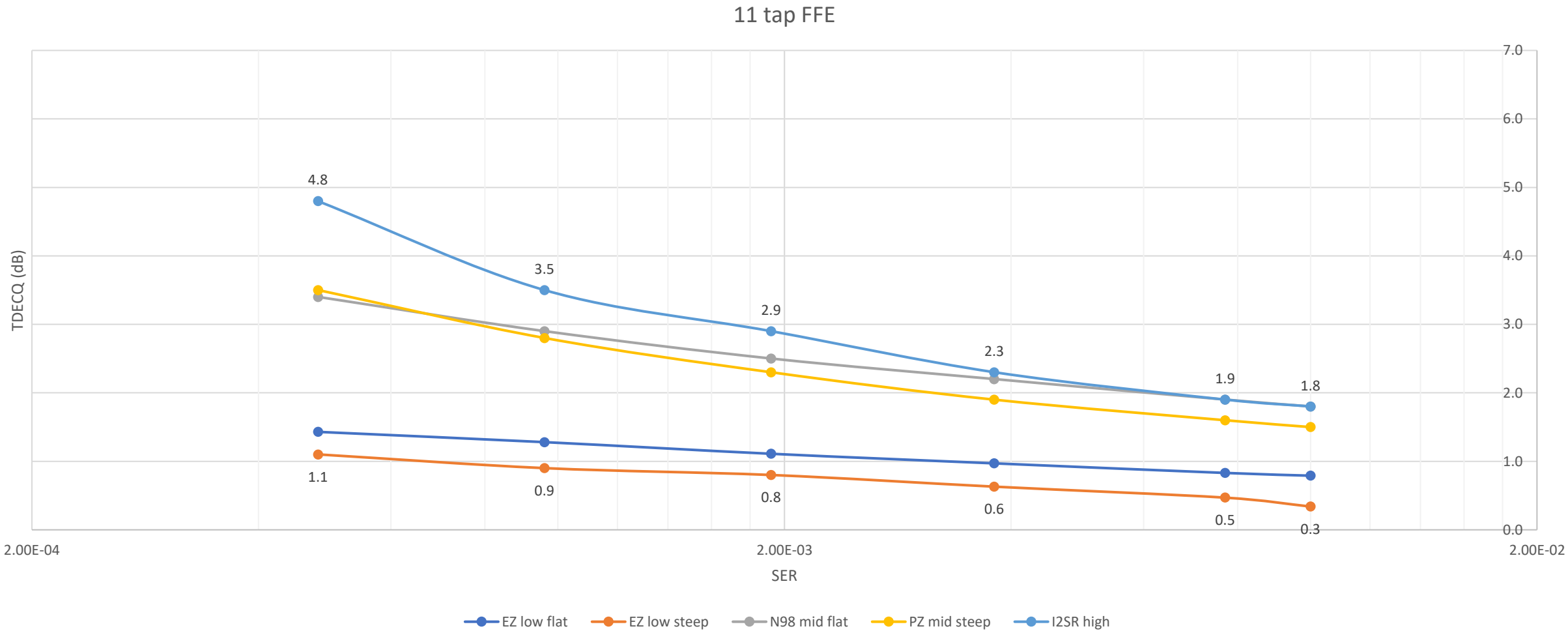
- Updates BER for FECi to 2e-3
  - Updates SER for FECi to 4e-3

- Updates to OMA Min to vary according to Max(TECQ,TDECQ)
  - Previously varied only according to TDECQ

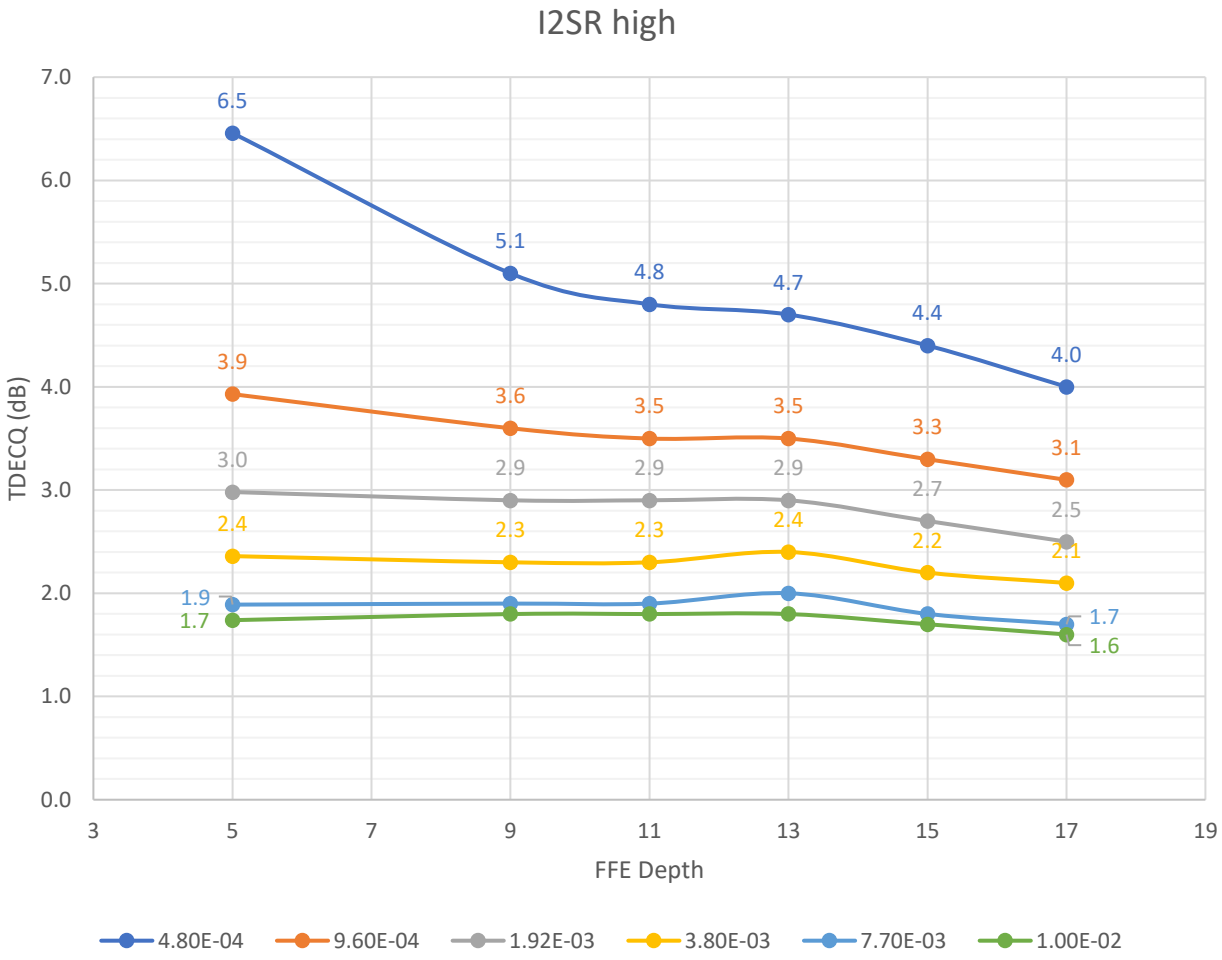
106GBD-PAM4 Measurements

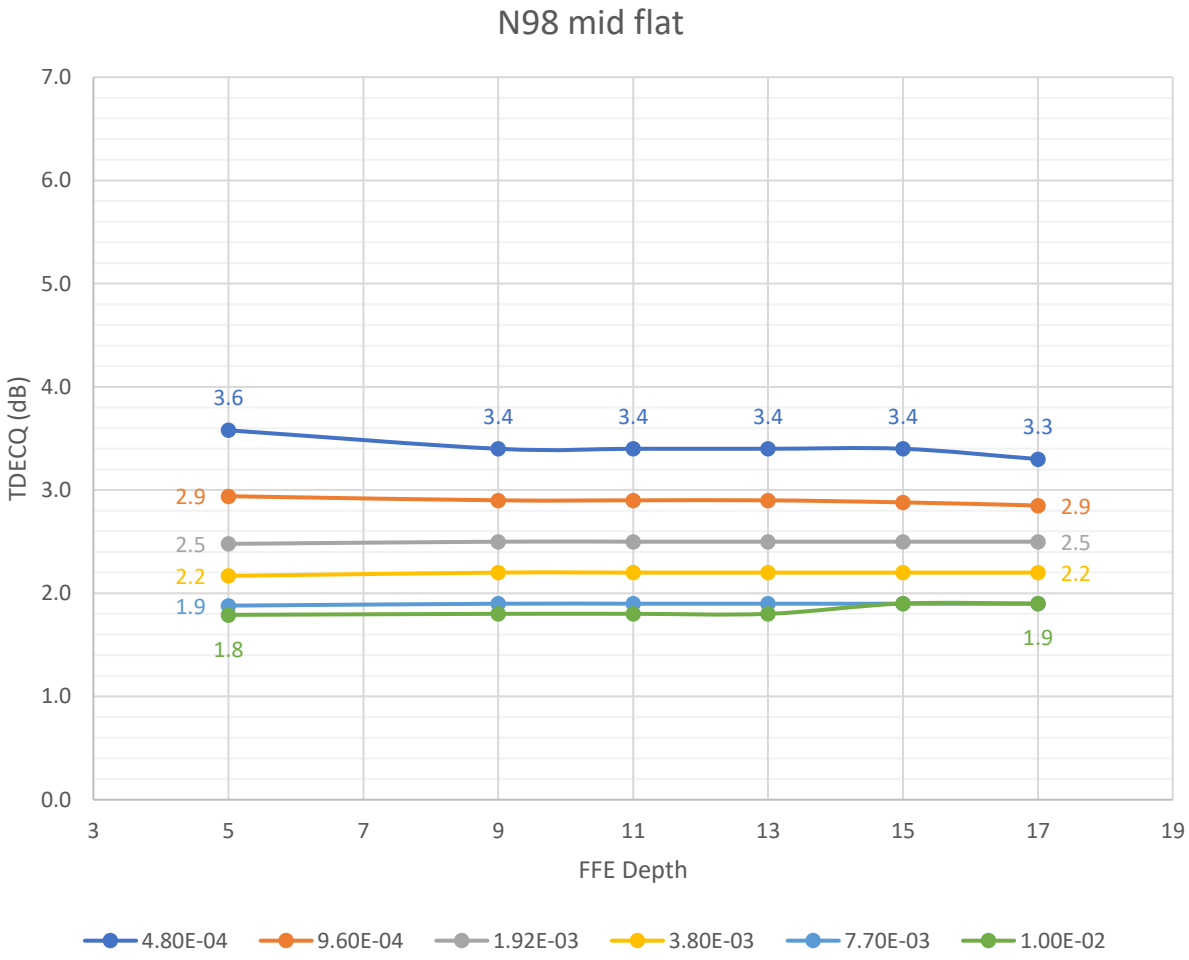
Curve selection taken from lecheminant_3dj_01b_2309.pdf

TDECQ vs. SER (Different Transmitters)



TDECQ vs. FFE (Different SER)





Changes to TDECQ/TECQ/SECQ Reference Receiver - Trends

- Higher TDECQ transmitters see improvements due to increasing SER or increasing FFE depth, however the combined effect of both is minimal.
  - Ie, TDECQ for high SER relatively flat even with increased FFE depth

- Lower TDECQ transmitters see improvements due to increasing of SER, however increasing of FFE depth seems to have minimal effect.
- Reference FFE depth of 11 taps seems to be a good depth
  - Provides greater absolute depth than FFE5 does for 100G/L
  - Early test results for 800G-LR4 transmitter with FFE11 reference show TDECQ values < 1 dB (liu_3dj_optx_01a_231019.pdf)

Changes to TDECQ/TECQ/SECQ Reference Receiver – Tap Restrictions

	Symbol	Value	Units
Feedforward equalizer (FFE) length	N_b	11	UI
Maximum FFE pre-cursors		3	UI
Maximum FFE post-cursors		9	UI
Normalized FFE coefficient maximum limit *n* = -3 *n* = -2 *n* = -1 *n* = 0 *n* = 1 *n* = 2 *n* ≥ 3	$bb_{max}(n)$	 TBD† TBD TBD TBD TBD TBD TBD†	-
Normalized FFE coefficient minimum limit *n* = -3 *n* = -2 *n* = -1 *n* = 0 *n* = 1 *n* = 2 *n* ≥ 3	$bb_{min}(n)$	 TBD† TBD TBD TBD TBD TBD TBD†	-
Sum of all tap weights	bb_{sum}	1	

† Coefficients at +/- 3 and beyond expected to be small

Changes to BER for FECi

- BER of 4.8e-3 represents the best-case SD-FEC performance for the adopted Hamming(128,120) code with 12-way convolutional interleaving.
  - This would correlate to a target SER of 9.6e-3
- Actual implementation may have a lower level of performance (and can afford to for 500m and 2km links).
- Proposal is to use a BER of 2e-3 for 500m and 2km objectives, with a corollary target SER of 4e-3 for TDECQ/TECQ/SECQ measurements.

Changes to OMA Min

- In 802.3bs original effective lower limit for 400GBASE-DR4 TDECQ was 0.9 dB.
- This was later revised up to 1.4 dB during comment resolution.
  - P802d3bs_D3p3_comments_final_Cl.pdf (Page 18)
- This was predicated by the change in reference EQ type from T/2 to T-spaced, and the scaling of the reference filter bandwidth from 75% baud rate to 50% baud rate (king_3cd_01a_0717.pdf).
  - It was expected that a reference transmitter would be no better than 1.4 dB
- With the introduction of overshoot/undershoot limits and TECQ (to prevent over-emphasis in non-dispersive links) and in light of the TDECQ vs. Sensitivity results shared in lecheminant_3dj_01b_2309.pdf, the suggestion for 200G/L standards is to **revise back to 0.9 dB.**
- Applies to FECo and FECi.

Separate Optical Specifications

- Distinct PMD/PHY specifications being presented for FECo and FECi
  - Each with unique transmitter, receiver, and link specifications

- No IEEE requirement for interoperability between the two
  - Ie, FECi receiver does not have to interoperate with FECo transmitters.
  - Informative interoperability methods may still be advantageous

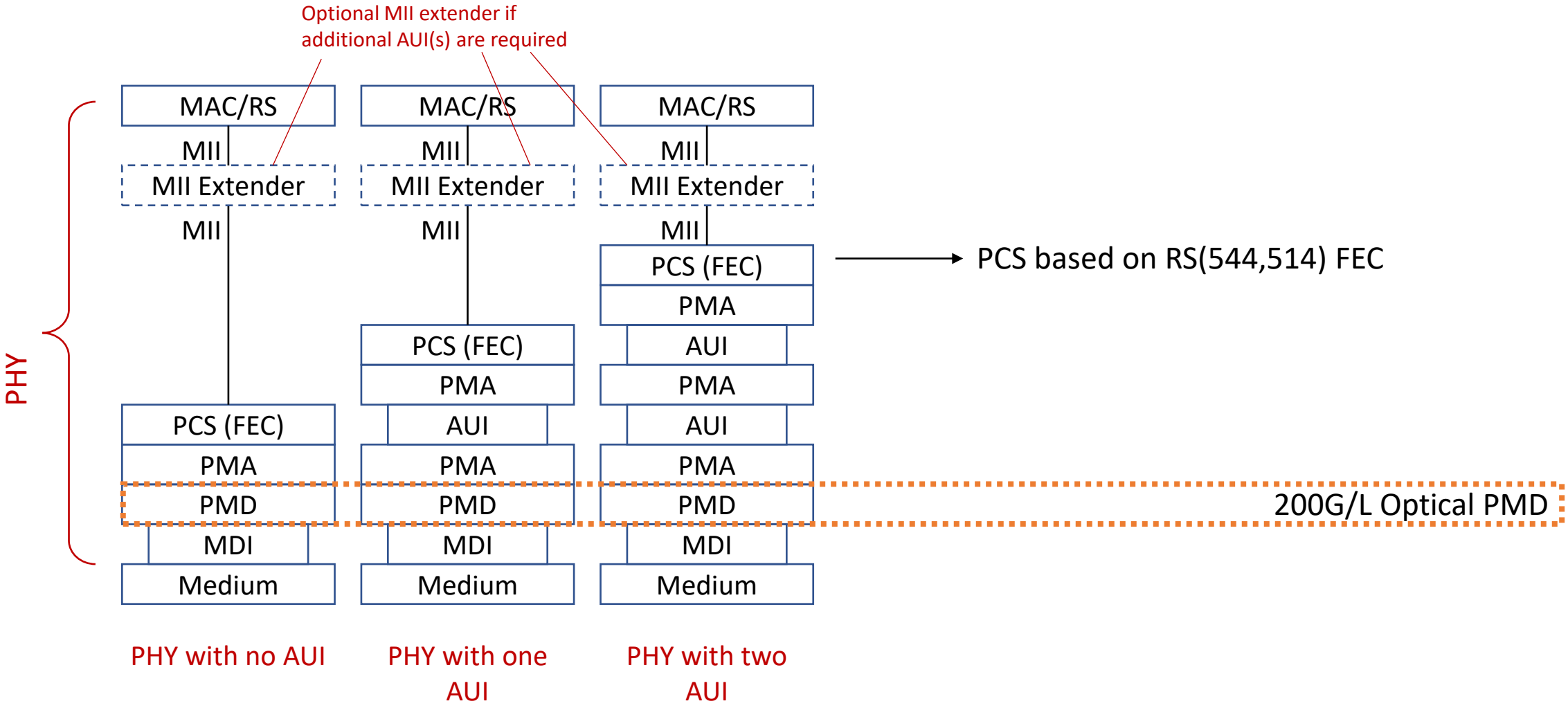
Temporary Nomenclature

- Appending suffix FECo or FECi to existing nomenclature.
- Example: 800GBASE-DR4 becomes 800GBASE-DR4-FECo and 800GBASE-DR4-FECi.
- Expectation is that final nomenclature may vary.

Optical Specifications for FECo

Single PMD

Location in Ethernet Stack: FECo



BER Requirements

- **FECo** : The BER of the PMD link shall be less than **2.4×10^{-4}** provided that the error statistics are sufficiently random that this results in a frame loss ratio of less than 1.7×10^{-12} for 64-octet frames with minimum interpacket gap when processed with an 800GBASE-R/1.6TBASE-R PCS.

- **Question**: While FLR has been the norm for 802.3, end users tend to look at FEC bin distributions/probabilities instead of FLR (expecting lower error counts at higher bin counts), do we need to replace or augment the FLR spec?

Proposed Transmitter Specifications

Description	200GBASE-DR1-FECo 400GBASE-DR2-FECo 800GBASE-DR4-FECo 1.6TBASE-DR8-FECo	200GBASE-FR1-FECo 400GBASE-DR2-2-FECo 800GBASE-DR4-2-FECo 1.6TBASE-DR8-2-FECo	800GBASE-FR4-FECo	Unit
Signaling rate, each lane (range)	106.25 ± 50 ppm	106.25 ± 50 ppm	106.25 ± 50 ppm	GBd
Modulation Format	PAM4	PAM4	PAM4	
Lane wavelengths (range)	1304.5 to 1317.5	1304.5 to 1317.5	1264.5 to 1277.5 1284.5 to 1297.5 1304.5 to 1317.5 1324.5 to 1337.5	nm
Side-mode suppression ratio (SMSR), (min)	30	30	30	dB
Average launch power, each lane (max)	4	4	4.9	dBm
Average launch power, each lane (min)	-2.8	-2.1	-1.8	dBm
Outer Optical Modulation Amplitude (OMA_{outer}), each lane(max)	4.2	4.2	4.8	dBm
Outer Optical Modulation Amplitude (OMA_{outer}), each lane(min) for MAX(TECQ,TDECQ) < 0.9 dB for 0.9 dB ≤ MAX(TECQ,TDECQ) ≤ 3.4 dB	 -0.3 -1.2 + MAX(TECQ,TDECQ)	 0.4 -0.5 + MAX(TECQ,TDECQ)	 0.8 -0.1+MAX(TECQ,TDECQ)	 dBm dBm
Transmitter and dispersion eye closure (TDECQ), each lane (max)	3.4[a]	3.4[a]	3.6[a]	dB
TECQ (max)	3.4[a]	3.4[a]	3.6[a]	dB
|TDECQ - TECQ| (max)	2.5[a]	2.5[a]	2.5[a]	dB
Average launch power of OFF transmitter, each lane (max)	-15	-15	-15	dBm
Extinction ratio, each lane, (min)	3.5	3.5	3.5	dB
Transmitter transition time (max)	8	8	8	ps
Transmitter over/under-shoot (max)	22	22	22	%
RIN_xOMA (max)	-139	-139	-139	dB/Hz
Optical return loss tolerance (max)	21.4 (15.5 for DR1)	21.4 (17.1 for FR1)	17.1	dB
Transmitter reflectance (max)	-26	-26	-26	dB

[a] Measured with FFE11 reference equalizer with SER = 4.8e-4

Proposed Receiver Specifications

Description	200GBASE-DR1-FECo 400GBASE-DR2-FECo 800GBASE-DR4-FECo 1.6TBASE-DR8-FECo	200GBASE-FR1-FECo 400GBASE-DR2-2-FECo 800GBASE-DR4-2-FECo 1.6TBASE-DR8-2-FECo	800GBASE-FR4-FECo	Unit
Signaling rate, each lane (range)	106.25 ± 50 ppm	106.25 ± 50 ppm	106.25 ± 50 ppm	GBd
Modulation Format	PAM4	PAM4	PAM4	
Lane wavelengths (range)	1304.5 to 1317.5	1304.5 to 1317.5	1264.5 to 1277.5 1284.5 to 1297.5 1304.5 to 1317.5 1324.5 to 1337.5	nm
Damage threshold, each lane	5	5	5.9	dBm
Average receive power, each lane (max)	4	4	4.9	dBm
Average receive power, each lane (min)	-5.8	-6.1	-5.6	dBm
Receive power, each lane (OMA_{outer}) (max)	4.2	4.2	4.8	dBm
Receiver reflectance (max)	-26	-26	-26	dB
Receiver sensitivity (OMA_{outer}), each lane (max) for TECQ < 0.9 dB for 0.9 dB ≤ TECQ ≤ SECQ	 -3.4 -4.3 + TECQ	 -4.0 -4.9 + TECQ	 -3.7 -4.6 + TECQ	 dBm dBm
Stressed receiver sensitivity (OMA_{outer}), each lane (max)	-0.9[a]	-1.5[a]	-1.0	dBm
Conditions of stressed receiver sensitivity test:				
SECQ	3.4[a,b]	3.4[a,b]	3.6[a]	dB
OMA_{outer} of each aggressor lane[c]	2.9	1.5	1.9	dBm

[a] Measured with FFE11 reference equalizer with SER = 4.8e-4
[b] No aggressors needed for 200GBASE-DR1-FECo or 200GBASE-FR1-FECo

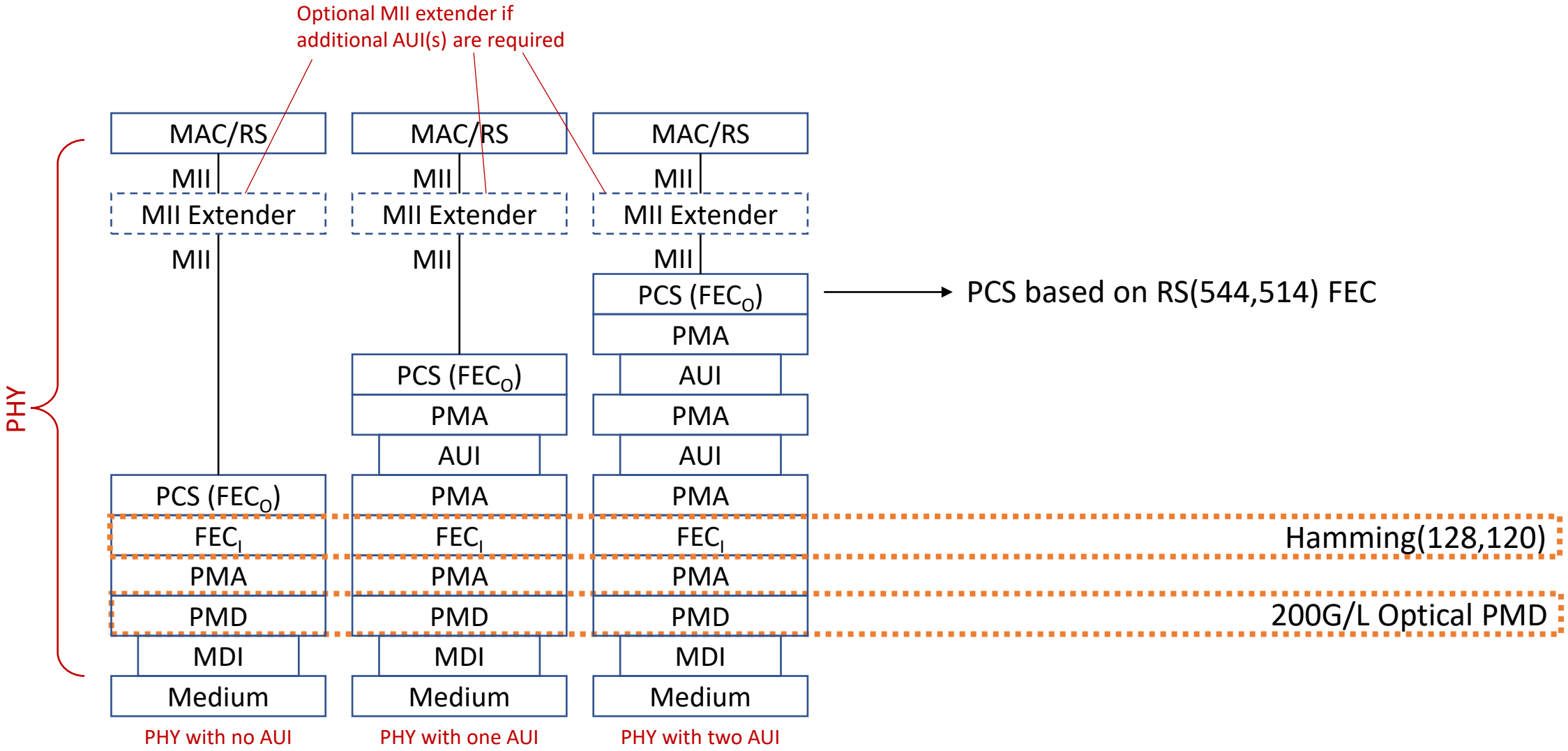
Proposed Link Budget

Description	200GBASE-DR1-FECo 400GBASE-DR2-FECo 800GBASE-DR4-FECo 1.6TBASE-DR8-FECo	200GBASE-DR1-FECo 400GBASE-DR2-FECo 800GBASE-DR4-FECo 1.6TBASE-DR8-FECo	800GBASE-FR4-FECo	Unit
Power budget (for max TDECQ)	6.5	7.8	8.1	dB
Operating distance	500	2000	2000	m
Channel insertion loss	3	4	4	dB
Maximum discrete reflectance	-35	-35	-35	dB
Allocation for penalties (for max TDECQ)	3.5	3.8	4.1	dB
Additional insertion loss allowed	0	0	0	dB

Optical Specifications for FECi

Single PMD

Location in Ethernet Stack: FECi



BER Requirements

- **FECi** : The BER of the PMD link shall be less than **2 x 10^{-3}** provided that the error statistics are sufficiently random that this results in a frame loss ratio of less than 1.7 x 10^{-12} for 64-octet frames with minimum interpacket gap when processed with an 800GBASE-R/1.6TBASE-R PCS and inner code FEC sublayer.

- **Question**: Can/should pre-FECi BER be specified at all?
  - No universal value: depends on SD-FEC implementation
  - Likely not measurable in optical modules

Proposed Transmitter Specifications

Description	200GBASE-DR1-FECi 400GBASE-DR2-FECi 800GBASE-DR4-FECi 1.6TBASE-DR8-FECi	200GBASE-DR1-FECi 400GBASE-DR2-FECi 800GBASE-DR4-FECi 1.6TBASE-DR8-FECi	800GBASE-FR4-FECi	Unit
Signaling rate, each lane (range)	113.4375 ± 50 ppm	113.4375 ± 50 ppm	113.4375 ± 50 ppm	GBd
Modulation Format	PAM4	PAM4	PAM4	
Lane wavelengths (range)	1304.5 to 1317.5	1304.5 to 1317.5	1264.5 to 1277.5 1284.5 to 1297.5 1304.5 to 1317.5 1324.5 to 1337.5	nm
Side-mode suppression ratio (SMSR), (min)	30	30	30	dB
Average launch power, each lane (max)	4	4	4.9	dBm
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Outer Optical Modulation Amplitude (OMA_{outer}), each lane(max)	4.2	4.2	4.8	dBm
Outer Optical Modulation Amplitude (OMA_{outer}), each lane(min) for MAX(TECQ,TDECQ) < 0.9 dB for 0.9 dB ≤ MAX(TECQ,TDECQ) ≤ TBD dB	 -0.3 -1.2 + MAX(TECQ,TDECQ)	 0.4 -0.5 + MAX(TECQ,TDECQ)	 0.8 -0.1 + MAX(TECQ,TDECQ)	 dBm dBm
Transmitter and dispersion eye closure (TDECQ), each lane (max)	TBD[a]	TBD[a]	TBD[a]	dB
TECQ (max)	TBD[a]	TBD[a]	TBD[a]	dB
|TDECQ - TECQ| (max)	TBD	TBD	TBD	dB
Average launch power of OFF transmitter, each lane (max)	-15	-15	-15	dBm
Extinction ratio, each lane, (min)	3.5	3.5	3.5	dB
Transmitter transition time (max)	8	8	8	ps
Transmitter over/under-shoot (max)	22	22	22	%
RIN_xOMA (max)	-139	-139	-139	dB/Hz
Optical return loss tolerance (max)	21.4 (15.5 for DR1)	21.4 (17.1 for FR1)	17.1	dB
Transmitter reflectance (max)	-26	-26	-26	dB

[a] Measured with FFE11 reference equalizer with SER = 4e-3

Proposed Receiver Specifications

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Signaling rate, each lane (range)	113.4375 ± 50 ppm	113.4375 ± 50 ppm	113.4375 ± 50 ppm	GBd
Modulation Format	PAM4	PAM4	PAM4	
Lane wavelengths (range)	1304.5 to 1317.5	1304.5 to 1317.5	1264.5 to 1277.5 1284.5 to 1297.5 1304.5 to 1317.5 1324.5 to 1337.5	nm
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Receive power, each lane (OMA_{outer}) (max)	4.2	4.2	4.8	dBm
Receiver reflectance (max)	-26	-26	-26	dB
Receiver sensitivity (OMA_{outer}), each lane (max) for TECQ < 0.9 dB for 0.9 dB ≤ TECQ ≤ SECQ	 -3.4 -4.3 + TECQ	 -4.0 -4.9 + TECQ	 -3.7 -4.6 + TECQ	 dBm dBm
Stressed receiver sensitivity (OMA_{outer}), each lane (max)	TBD	TBD	TBD	dBm
Conditions of stressed receiver sensitivity test:				
SECQ	TBD[a,b]	TBD[a,b]	TBD[a]	dB
OMA_{outer} of each aggressor lane[c]	TBD	TBD	TBD	dBm

[a] Measured with FFE11 reference equalizer with SER = 4e-3
[b] No aggressors needed for 200GBASE-DR1-FECi or 200GBASE-FR1-FECi

Proposed Link Budget

Description	200GBASE-DR1-FECi 400GBASE-DR2-FECi 800GBASE-DR4-FECi 1.6TBASE-DR8-FECi	200GBASE-DR1-FECi 400GBASE-DR2-FECi 800GBASE-DR4-FECi 1.6TBASE-DR8-FECi	800GBASE-FR4-FECi	Unit
Power budget (for max TDECQ)	TBD	TBD	TBD	dB
Operating distance	500	2000	2000	m
Channel insertion loss	3	4	4	dB
Maximum discrete reflectance	-35	-35	-35	dB
Allocation for penalties (for max TDECQ)	TBD	TBD	TBD	dB
Additional insertion loss allowed	0	0	0	dB

Summary

- Baseline proposals for all 200G/L objectives at 500m and 2km have been proposed.

- Proposals contain requirements for operation with and without an inner FEC

Open Questions – Call for Data

- TDECQ max values for FECi left open pending full link stress testing (ie, max TDECQ for functional link). Do we know when such data might become available?

- How much margin is needed (above BER) for clock recovery/lock for FECi?
  - IE, If data recovery occurs at BER 2e-3 at what level must clock recovery occur (and does that require any additional specifications)?

Thank You