Chirp characteristics and chromatic dispersion tolerance of 200G EML transmitters

John Johnson

IEEE 802.3df 200 Gb/s, 400 Gb/s, 800 Gb/s, and 1.6 Tb/s Ethernet Task Force

October 11, 2022

Introduction

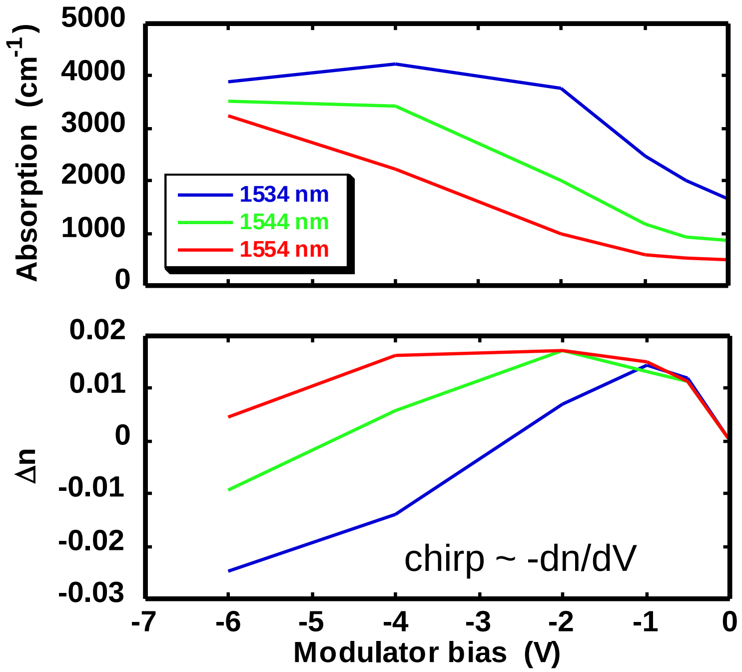
- Transmitter chirp becomes increasingly important to transmission performance as baud rate increases due to the stronger effect of chromatic dispersion (CD).
- Modeling of transmitter chirp often assumes it is constant over the driver swing (small signal approximation). This is appropriate for MZ transmitters, but not EA modulated transmitters, and could result in inaccurate predictions of chromatic dispersion tolerance for EMLs.
- This contribution presents simulations of 112.5 GBd transmission using typical EML chirp characteristics with the EA bias voltage adjusted to increase CD tolerance.
- The simulations predict that there is sufficient chromatic dispersion tolerance for the 800GBASE-FR4 objective using CWDM EML transmitters with TDECQ < 3.4dB.
- Extending the results to 10km for the 800GBASE-LR4 objective, a usable wavelength range of 1300.8 to 1315.8 nm (2.63 THz) is obtained for EML-based transmitters for TDECQ < 3.9dB.

Chirp behavior of EA modulators

- The absorption and chirp of an EA modulator are linked mathematically by the Kramers-Krönig relation.
- Chirp is positive at low absorption, passes through zero and becomes negative at higher absorption. The detailed shapes are dependent on the specific quantum well design.
- The EA bias voltage and swing must be selected to simultaneously achieve OMA, ER, TECQ and CD penalty objectives.
- These concepts were previously introduced in Johnson_optx_01a_0319

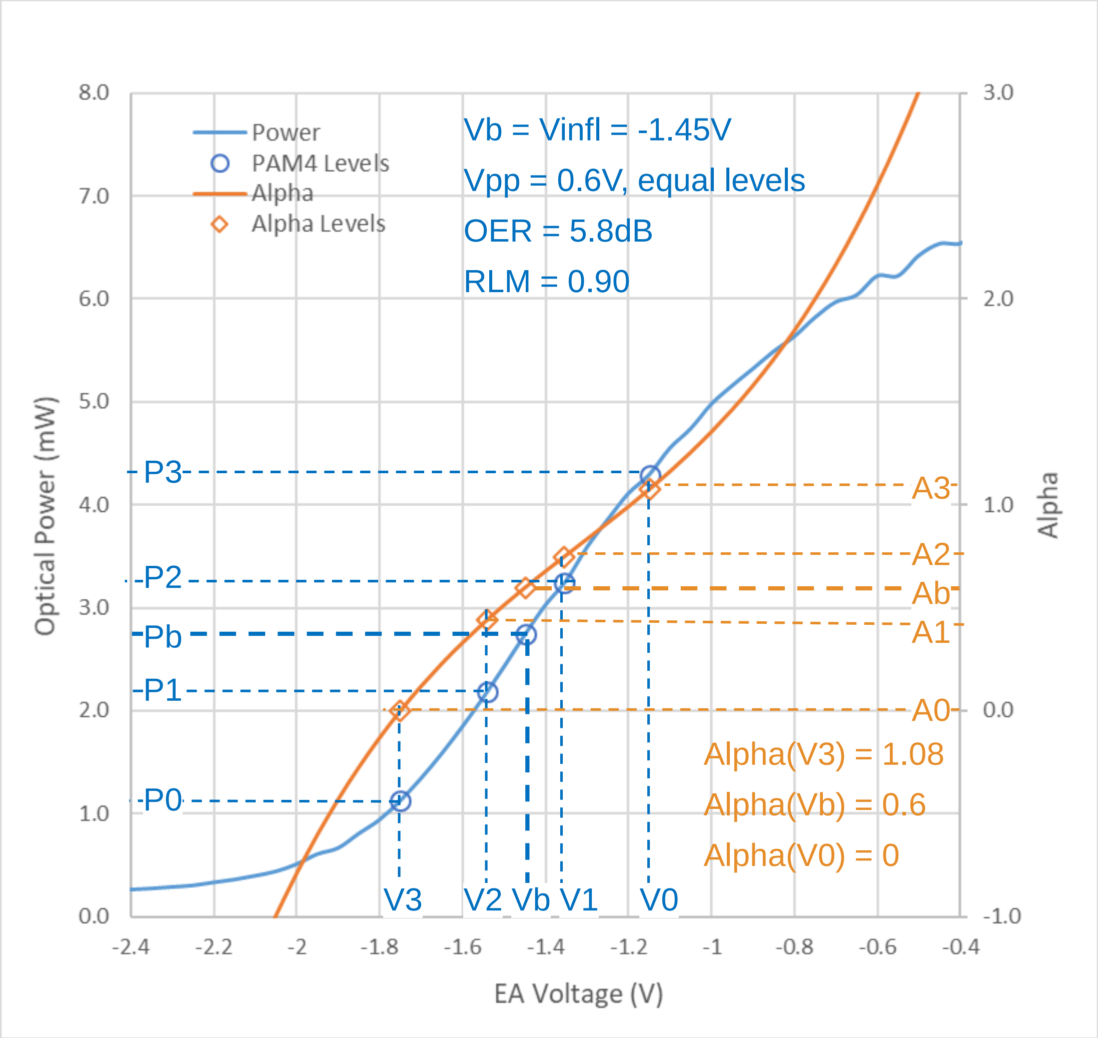
$$\Delta n = \frac{\pi}{c} PV \int_0^\infty \frac{\alpha(\omega')}{\omega'^2 - \omega^2} d\omega'$$

$$\Delta\omega = -\frac{d\phi(t)}{dt} = -\frac{\omega_o}{c}\frac{dn}{dV}\frac{dV(t)}{dt}$$



EAM extinction and chirp example

- For linear PAM4 modulation, the EA bias is typically set at the linear inflection voltage of the extinction curve (Vinfl)
- The details vary with the EAM design, but the voltage for zero chirp (alpha) is typically more negative than Vinfl
- Over the large-signal PAM4 drive voltage, alpha goes from a minimum at the 0-level, to a maximum at the 3-level.
- Alpha at the DC bias voltage (Vb) is not necessarily representative of the chirp at all PAM4 levels – constant alpha approximation may under-estimate the CD penalty.
- Alpha can be increased or decreased by shifting Vb away from Vinfl, requiring uneven drive levels to linearize the optical levels, but TECQ, ER or RX Sensitivity may degrade.
- For this study, measured EAM extinction and alpha curves were fit with polynomials for use in 112.5GBd transmission simulations



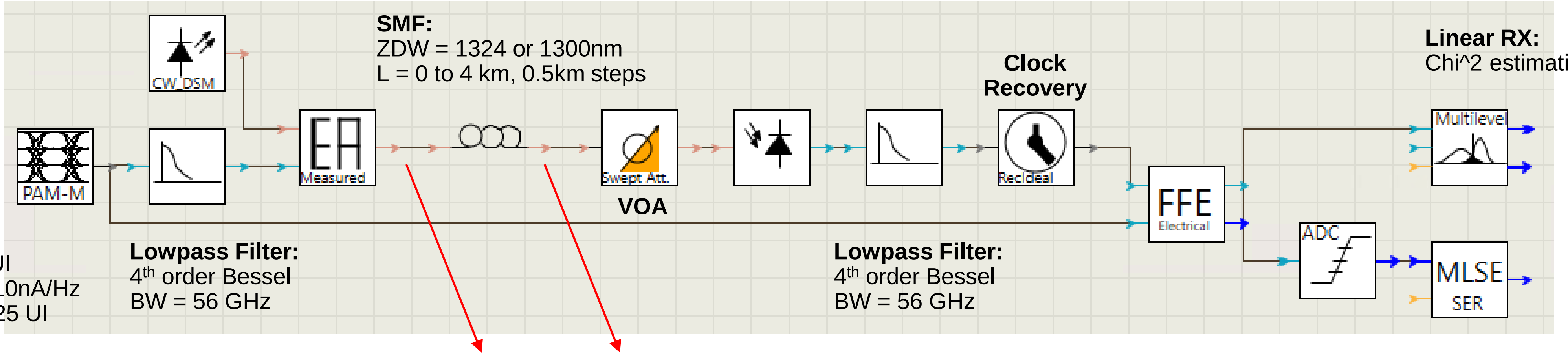
Transmission simulation parameters

CW Laser:
WL = 1264.5 or 1337.5 nm
Linewidth = 10MHz
RIN = -145 dB/Hz

EA Modulator:
Polynomial fit to measured extinction and alpha data

PIN Receiver:
Thermal noise = 20pA/Hz

FFE:
Samples/symbol = 1
Taps = 15 (5 pre)



SMF:
ZDW = 1324 or 1300nm
L = 0 to 4 km, 0.5km steps

Clock Recovery

Linear RX:
Chi^2 estimation

VOA

PAM4 coder:
PRBS23
Rise time = 0.2 UI
Current noise = 10nA/Hz
RMS Jitter = 0.025 UI

Lowpass Filter:
4th order Bessel
BW = 56 GHz

Lowpass Filter:
4th order Bessel
BW = 56 GHz

TECQ **TDECQ**

B/2 BT4 with 5 tap FFE

ADC (ideal):
1 sample/symbol

MLSE RX:
Levels = 4
Length = 8
States = 2

112.5 GBd PAM4

64 samples/symbol

32 runs x 2^{15} = 2^{20} symbols (MLSE SER floor = 9.5E-7)

Pre-FEC SER = 2E-3 assumed

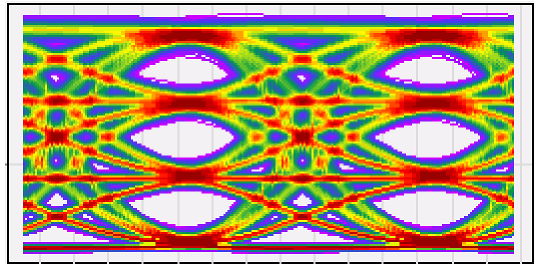
Positive dispersion: WL = 1337.5nm, ZDW = 1300nm

Linear bias condition (Vb = Vinfl)

Vb = -1.45V, Vpp = 0.6V, PAM4 levels = [0 1 2 3]

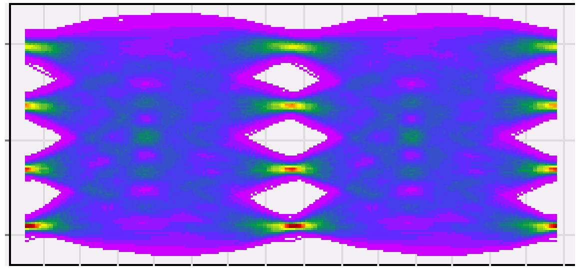
Alpha(Vb) = 0.60, Alpha = [0.0 0.43 0.76 1.08]

TX out (High BW)



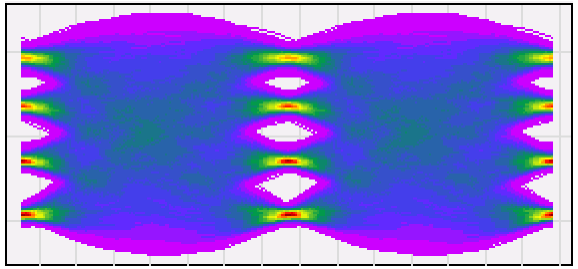
OER = 5.8dB

0km



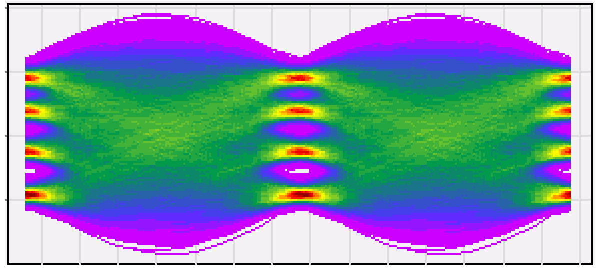
TECQ = 1.42dB

2km, 6.7ps/nm



TDECQ = 2.69dB

4km, 13.4ps/nm



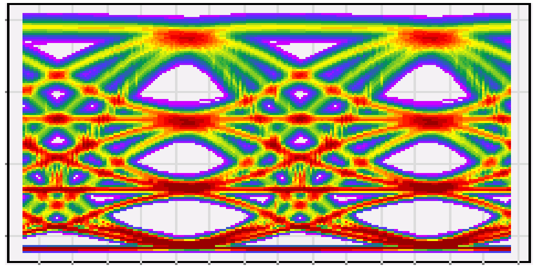
TDECQ = 13.2dB

More negative chirp condition (Vb < Vinfl)

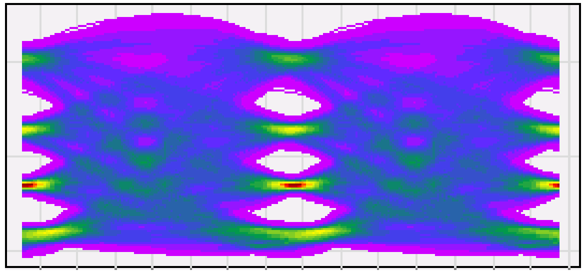
Vb = -1.75V, Vpp = 0.5V, PAM4 levels = [0 1.37 2.18 3]

Alpha(Vb) = 0, Alpha = [-0.78 -0.05 0.26 0.51]

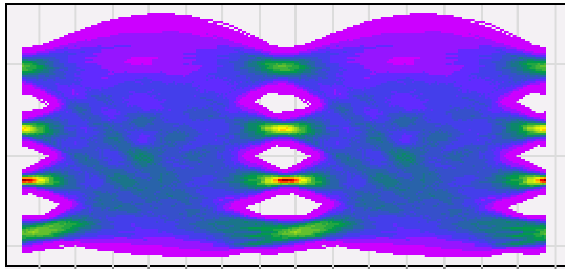
TECQ is degraded by 1dB, but TDECQ is significantly improved at high dispersion



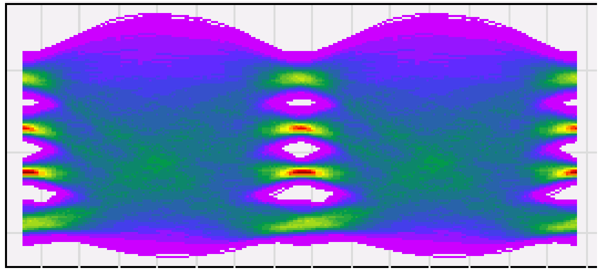
OER = 6.7dB



TECQ = 2.42dB



TDECQ = 2.31dB



TDECQ = 3.58dB

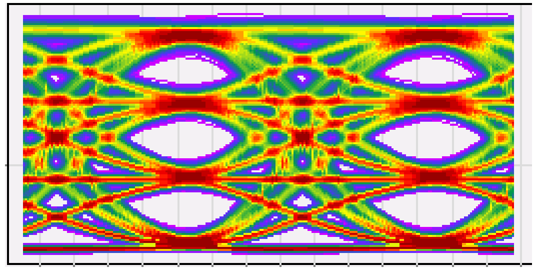
Negative dispersion: WL = 1264.5nm, ZDW = 1324nm

Linear bias condition (Vb = Vinfl)

Vb = -1.45V, Vpp = 0.6V, PAM4 levels = [0 1 2 3]

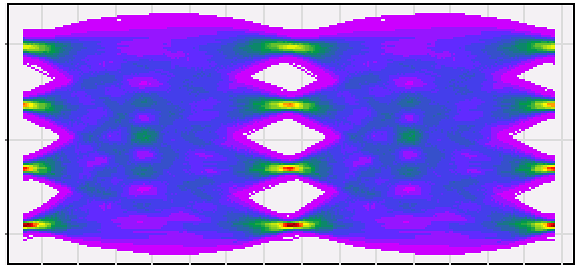
Alpha(Vb) = 0.60, Alpha = [0.0 0.43 0.76 1.08]

TX out (High BW)



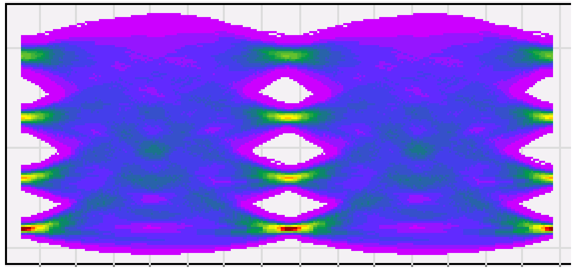
OER = 5.8dB

0km



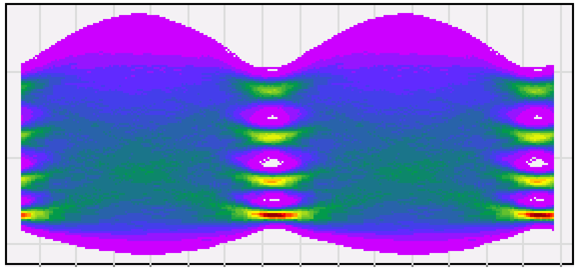
TECQ = 1.42dB

2km, -11.9ps/nm



TDECQ = 1.61dB

4km, -23.7ps/nm



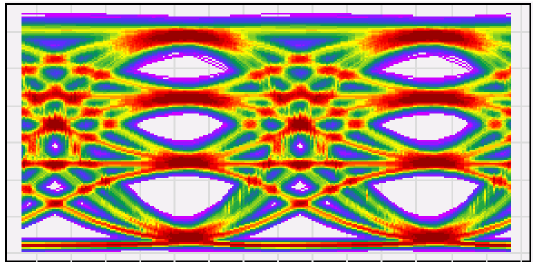
TDECQ = 9.97dB

More positive chirp condition (Vb > Vinfl)

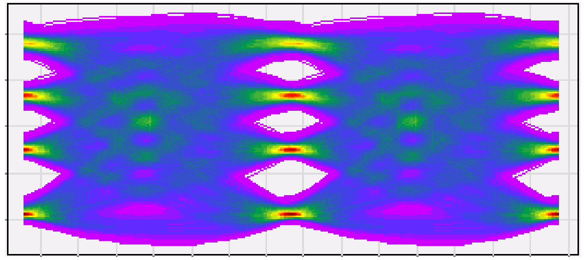
Vb = -1.25V, Vpp = 0.7V, PAM4 levels = [0 0.98 1.89 3]

Alpha(Vb) = 0.91, Alpha = [0.33 0.72 1.06 1.58]

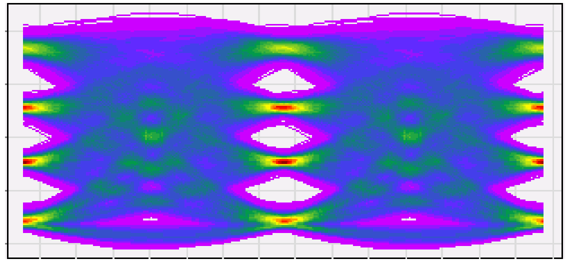
TECQ is degraded by 0.3dB, but TDECQ is significantly improved at high dispersion



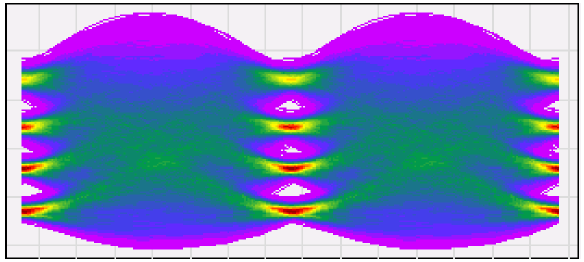
OER = 4.4dB



TECQ = 1.74dB

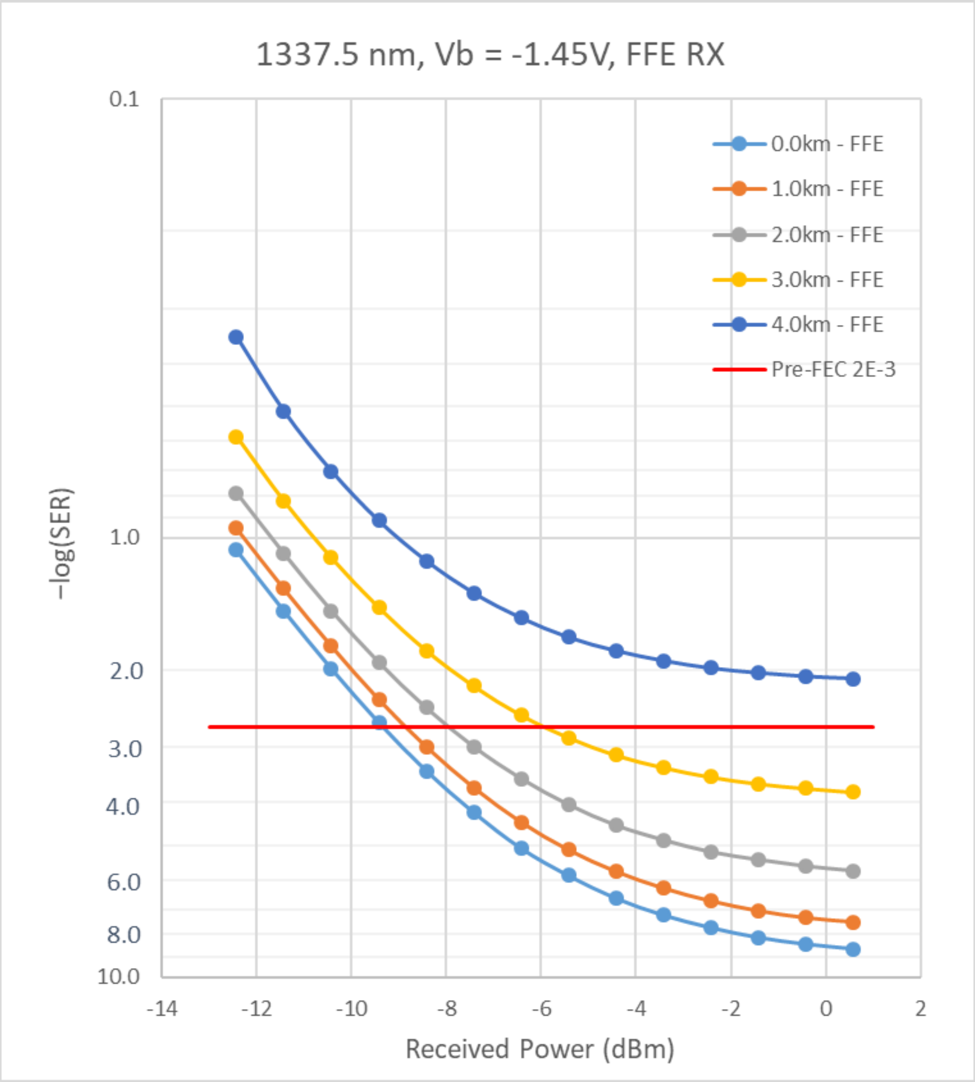


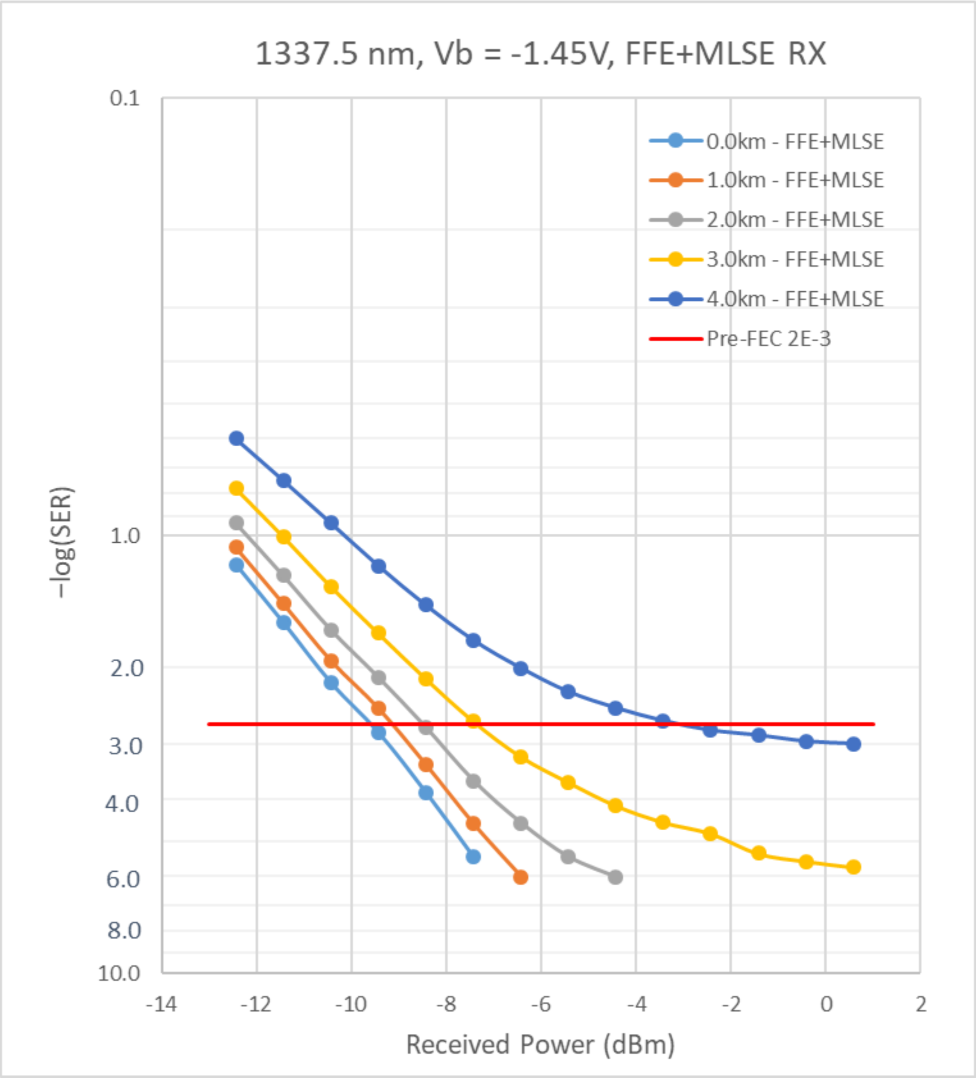
TDECQ = 1.12dB



TDECQ = 4.91dB

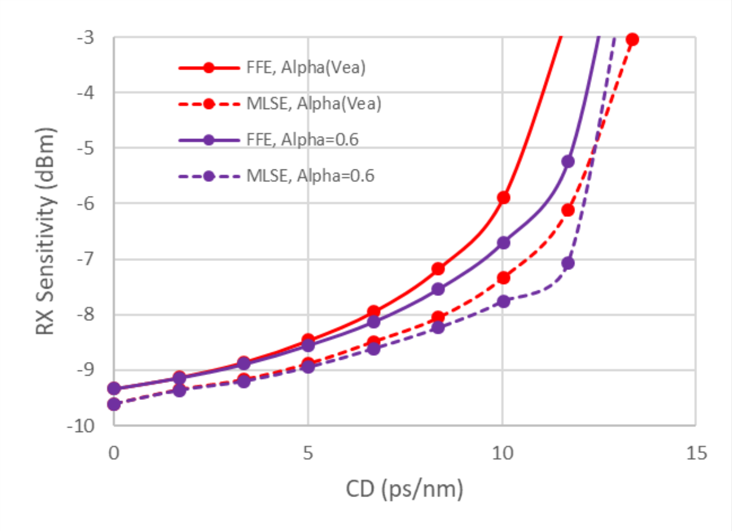
Sample SER waterfall curves

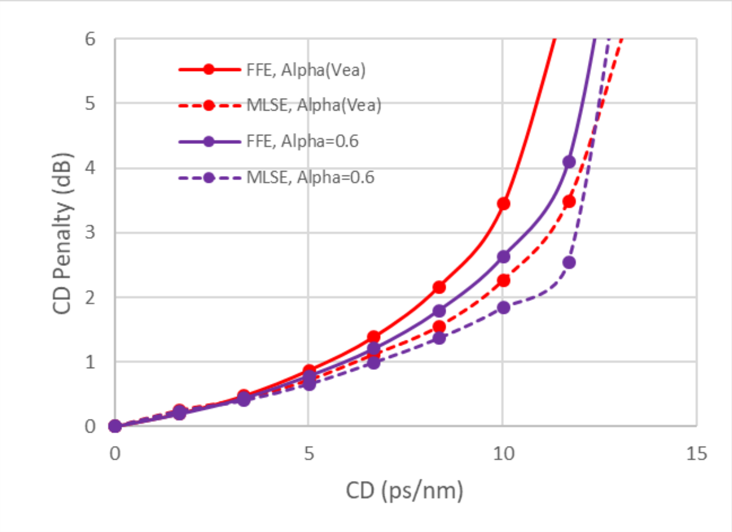




Comparison of variable and constant alpha

1337.5nm, Vb = Vinfl

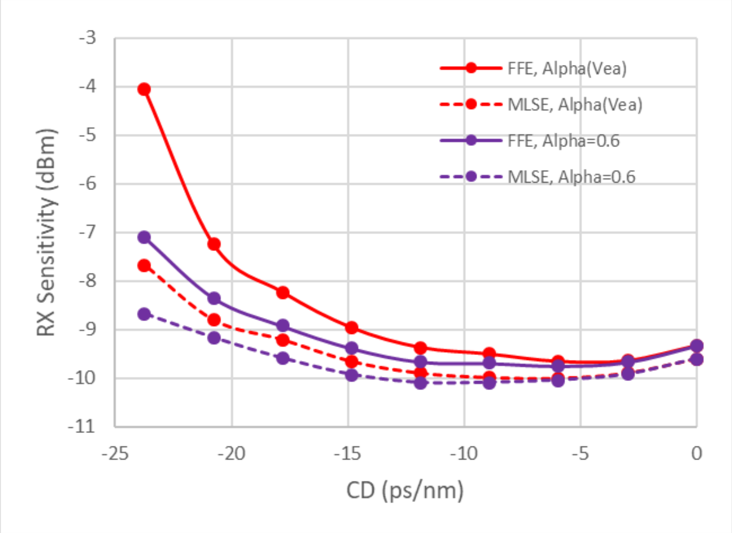


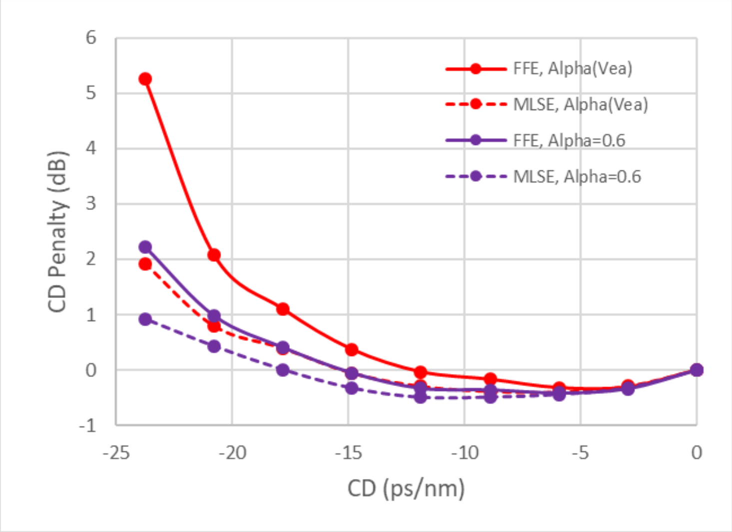


The constant Alpha approximation under-estimates RX Sensitivity and CD Penalty at both positive and negative dispersion limits

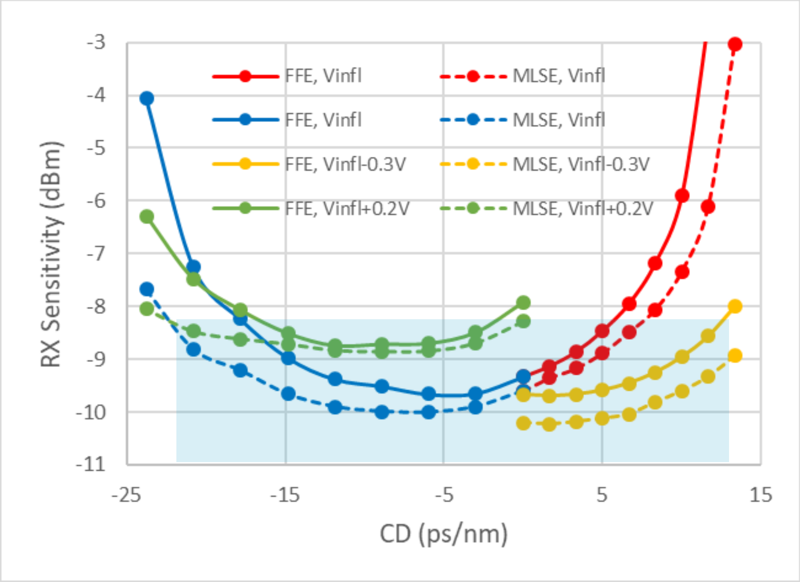
The error becomes larger for larger CD

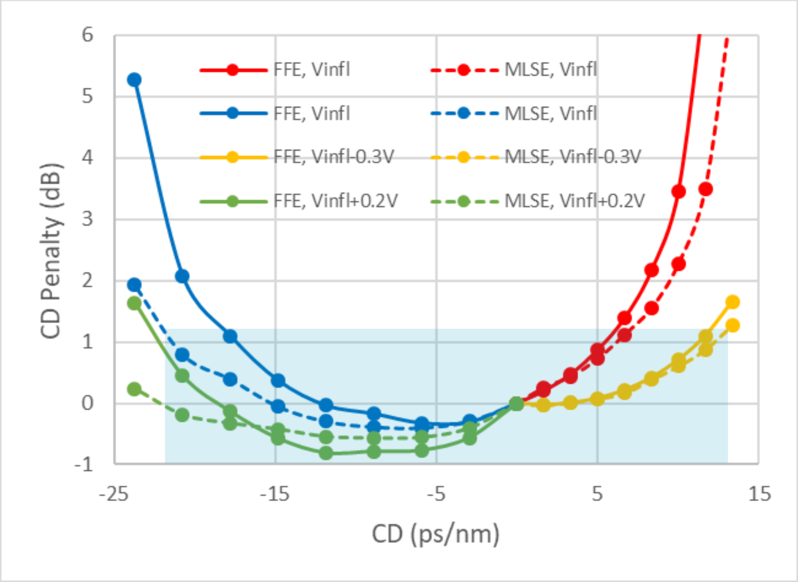
1264.5nm, Vb = Vinfl

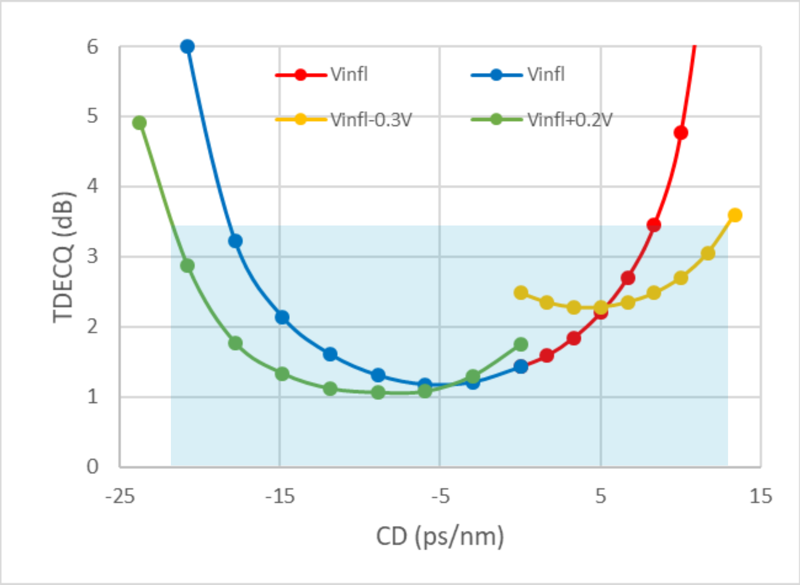


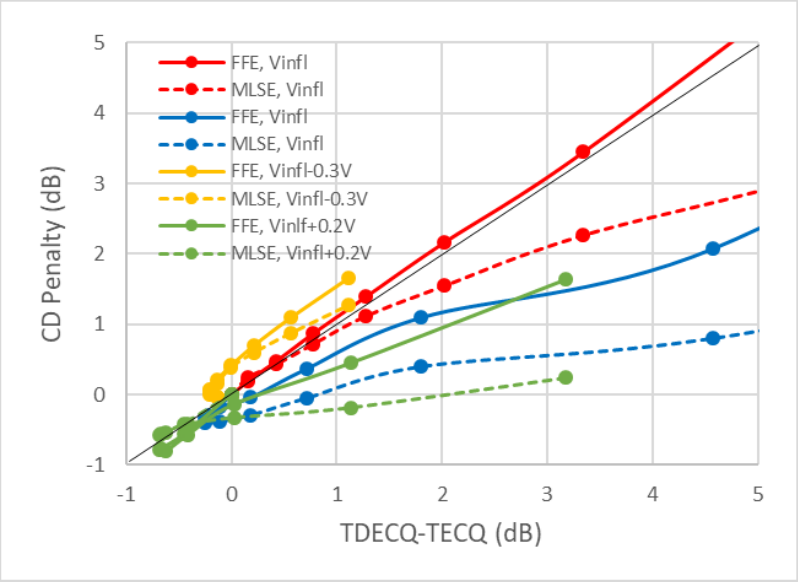


Simulated CWDM Transmission Results



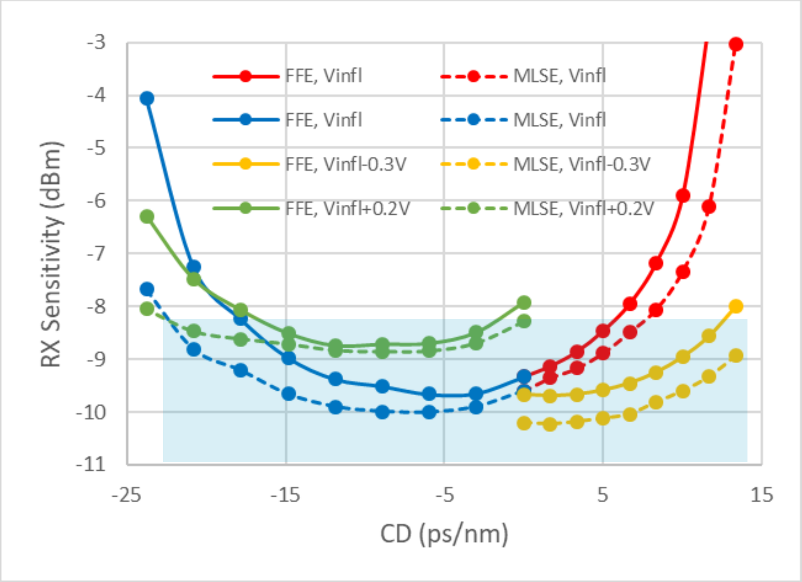


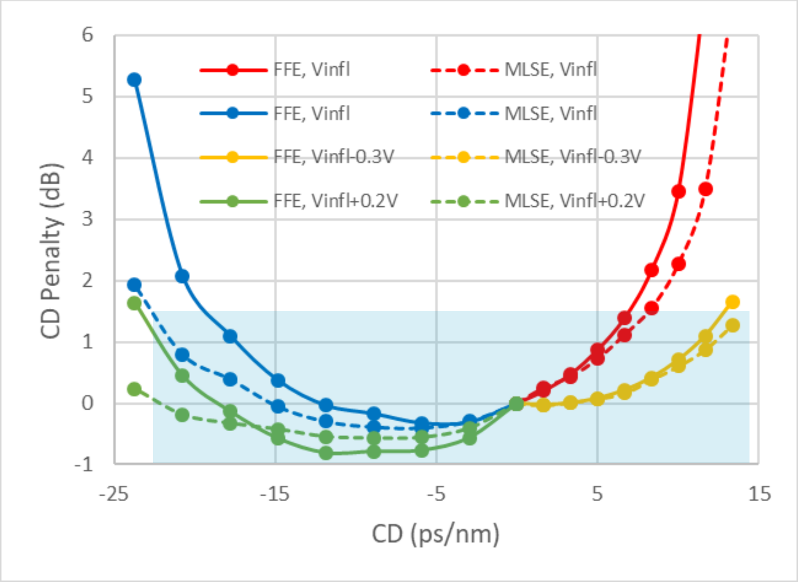


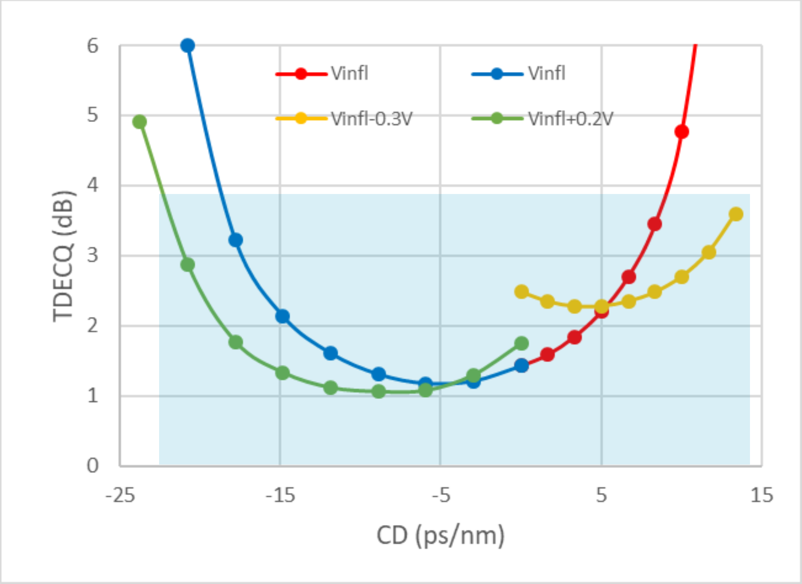


- Biasing more negative for lower chirp is necessary to reduce TDECQ and CD Penalty for the 1330nm channel at 2km
- Biasing more positive for more positive chirp is less necessary for the 1270nm channel, but can improve TDECQ and CD Penalty at the expense of B2B Sensitivity
- TDECQ < 3.4dB is achieved over -21.5 to +12.8 ps/nm CD, supporting up to 3.5km CWDM transmission
- Using FFE+MLSE RX, through fiber Sensitivity < -8.3dBm and CD Penalty < 1.2 dB is achieved with this RX model
- TDECQ minus TECQ overestimates CD penalty for negative dispersion

Implications for 800GBASE-LR4







- Note that the wavelength at negative dispersion is limited by TDECQ, not Sensitivity, due to the pulse narrowing caused by negative dispersion
- TDECQ is increasing rapidly at this lower limit, so actual implementation results could have significant variability

- TDECQ < 3.9dB is achieved over a CD range of approx. -22.2 to +14.3 ps/nm
- Using FFE+MLSE RX, CD Penalty is < 1.5 dB over the same CD range
- This range of CD gives a usable wavelength range of 1300.8 to 1315.8 nm for worst case 10km fiber, which is a frequency range of 2.63 THz
- This wavelength range is minimally sufficient to support 800GHz channel spacing with ±100GHz laser frequency tolerance

Conclusions

- Simulations using ideal TX and RX frequency response with 56GHz bandwidth and typical EAM Alpha characteristics results in good margin to an upper TDECQ limit of 3.4dB for worst case CWDM 2km chromatic dispersion.
  – Biasing the EAM more negative than the linear inflection voltage reduces Alpha and helps increase margin for worst case positive CD.
  – At worst case 2km CD (-11.9/+6.7 ps/nm), using the realistic Alpha(Vea) characteristics results in up to 0.3 dB higher CD penalty for FFE RX and 0.2 dB for FFE+MLSE RX, compared with using constant Alpha equal to the value at the bias voltage.
- The simulations with Alpha(Vea) predict TDECQ < 3.9dB over a maximum CD range of -22.2/+14.3 ps/nm.
  – Using the realistic Alpha(Vea) characteristics over this range results in up to 1.1dB higher CD penalty for FFE RX and 0.42 dB higher CD penalty for FFE+MLSE RX compared with using Alpha equal to the value at the bias voltage.
  – This results in a usable wavelength range of 1300.8 to 1315.8 nm for worst case 10km fiber, which is minimally sufficient for 4x800GHz channel spacing.
  – Less ideal TX frequency response would increase TDECQ and limit the usable CD range.
  – Use of pre-FEC SER > 2E-3 would increase the usable LR4 wavelength range.

Thank you!