Channel Metrics for EDC-based 10GBASE-LRM

Sudeep Bhoja - Big Bear Networks

Contributions and support:

Lars Thon	Aeluros
Andre Van Schyndel	Bookham
Paul Voois, Norm Swenson, Tom Lindsay	Clariphy
Jim Morris	Digital Optics
Lew Aronson	Finisar
Henry Wong, Ryan Latchman	Gennum
Matin Lobel, Jesper Hanberg	Intel
John Ewen, Eric Borisch	JDSU
Yi Sun	OFS Fitel
Petre Popescu	Quake
Abhijit Shanbhag	Scintera
Kevin Witt	Vitesse

Outline

- Channel Metrics
  - Background
  - Proposed PIE metric
  - Comparison with IFR
  - PIE metrics distribution
    - OSL
    - Vortex

Channel Metric Problem Statement

- 3dB bandwidth is not a good predictor of EDC dispersion penalty
- Do simple closed form channel metrics exist?
  - Extensively studied in the literature
  - No single metric can accurately predict dispersion penalty for all types of EDC
  - However, a pair can accurately predict dispersion penalty for
    - Linear Equalizer
    - Decision Feedback Equalizer

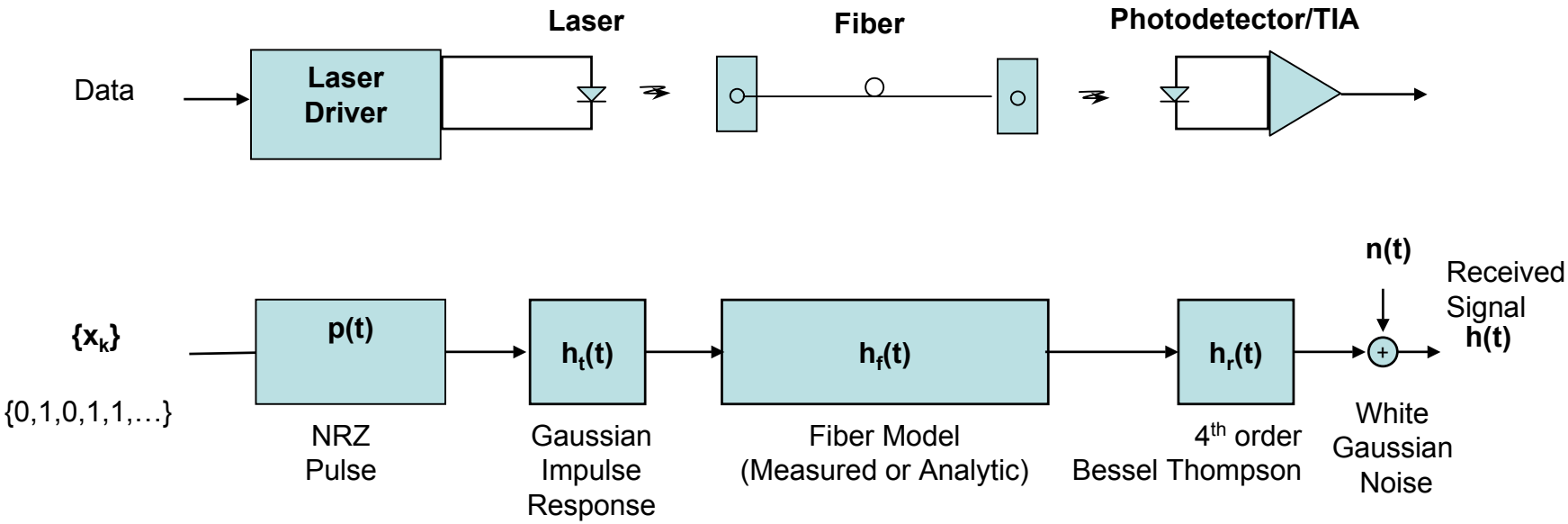
PIE – Channel Metric

- Available Dispersion budget 6dBo (dawe_1_0504.pdf)
  - 4.5dBo penalty allocated to ideal infinite length Equalizer
  - 1.5dBo EDC implementation penalty
- PIE – Penalty of Ideal Equalizer
  - Infinite taps are assumed
  - Minimum Mean Square Error
  - Implementation independent
- 2 channel metrics are described
  - PIE-L < 4.5dBo: Ideal Linear Equalizer
  - PIE-D < 4.5dBo[1]: Ideal Decision Feedback Equalizer
- Simple closed form integral expression exists for PIE
  - Well described in literature[2]. See also cunningham_0104.pdf

1 – This number may be lower do to higher EDC implementation penalty (DFE error propagation penalty etc) relative to PIE-L

2 - Lee & Messerschmitt, Chapter 10

Channel Model Assumptions



- Assumed Tx rise time is 47.1ps (20-80%)
- Rx is 4th order Bessel Thompson with 7.5GHz BW.
- Composite pulse response $h(t) = p(t) * h_t(t) * h_f(t) * h_r(t)$
- Sampled (folded) freq response of match filter o/p $h(t) * h(-t)$

$$\left|H_a(f)\right|^2 = \frac{1}{T}\sum_{n=-\infty}^{n=\infty}\left|H\left(f+\frac{n}{T}\right)\right|^2$$

PIE – Channel Metric

$$LE = 2T \int_0^{\frac{1}{2T}} \frac{df}{\frac{1}{T}|H_a(f)|^2 + \sigma^2}$$

$$DFE = e^{2T \int_0^{\frac{1}{2T}} \ln\left[\frac{1}{\frac{1}{T}|H_a(f)|^2 + \sigma^2}\right] df}$$

σ^2 is a constant based on the allocated dispersion penalty and set to $10^{(-17-2*6)/10}$

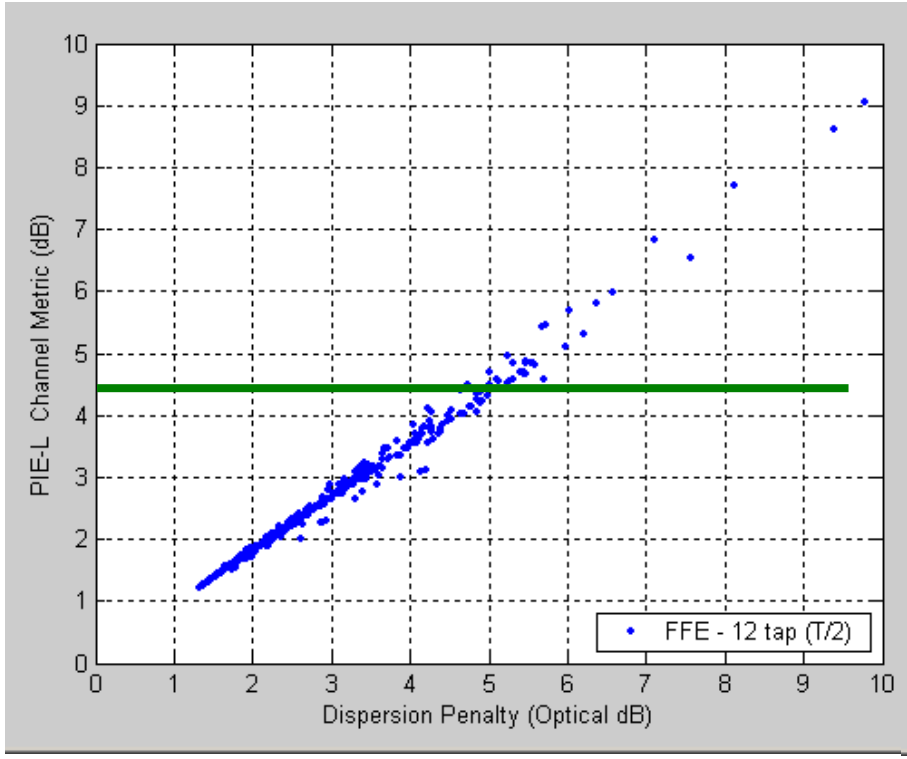
- 17dB is the required Electrical SNR for 1E-12 BER
- 6dBo is the allocated optical dispersion penalty

Dispersion penalty (dBo) of an ideal infinite length equalizer

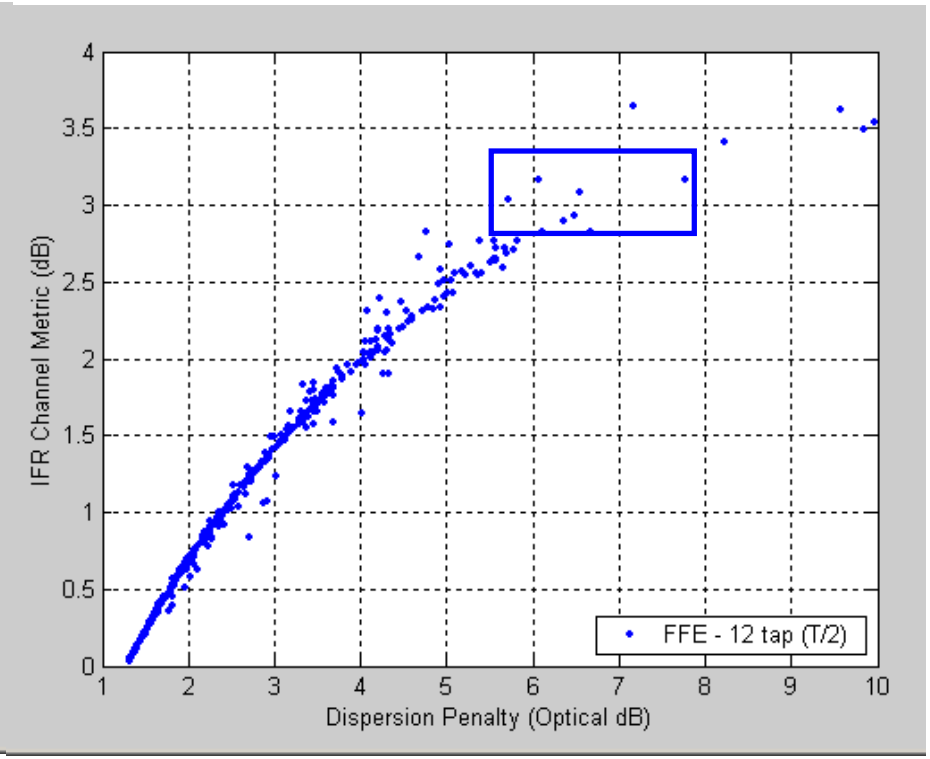
- PIE-L = 0.5*10*log10(LE)
- PIE-D = 0.5*10*log10(DFE)

Equations are derived in Lee & Messerschmitt, Chapter 10

PIE-L Channel Metric

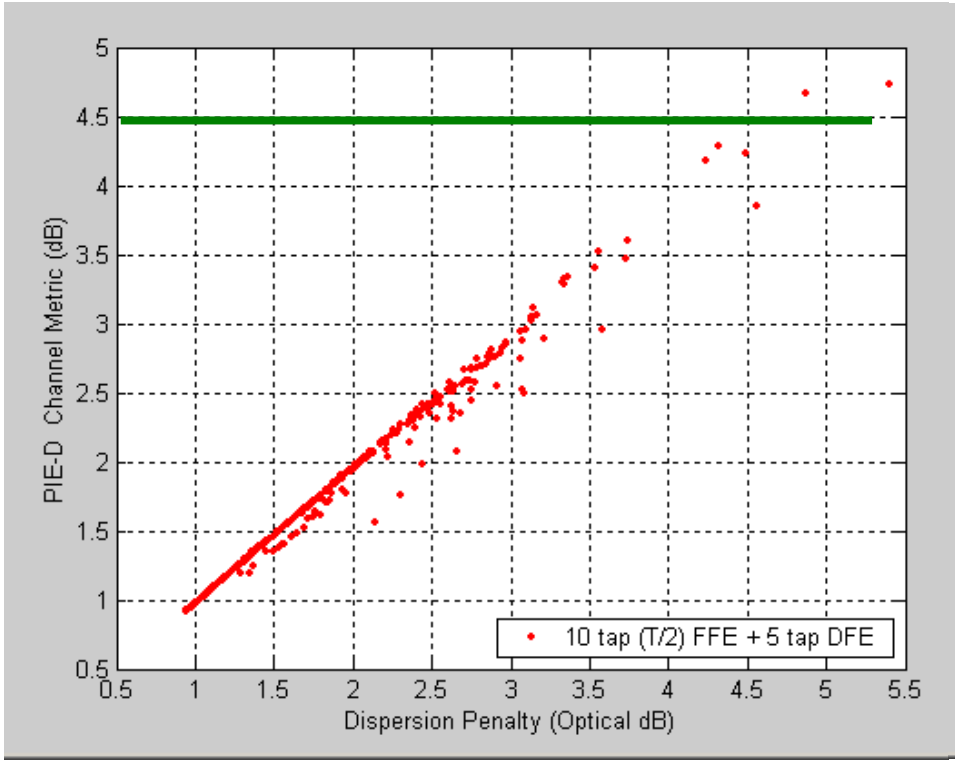


IFR Channel Metric

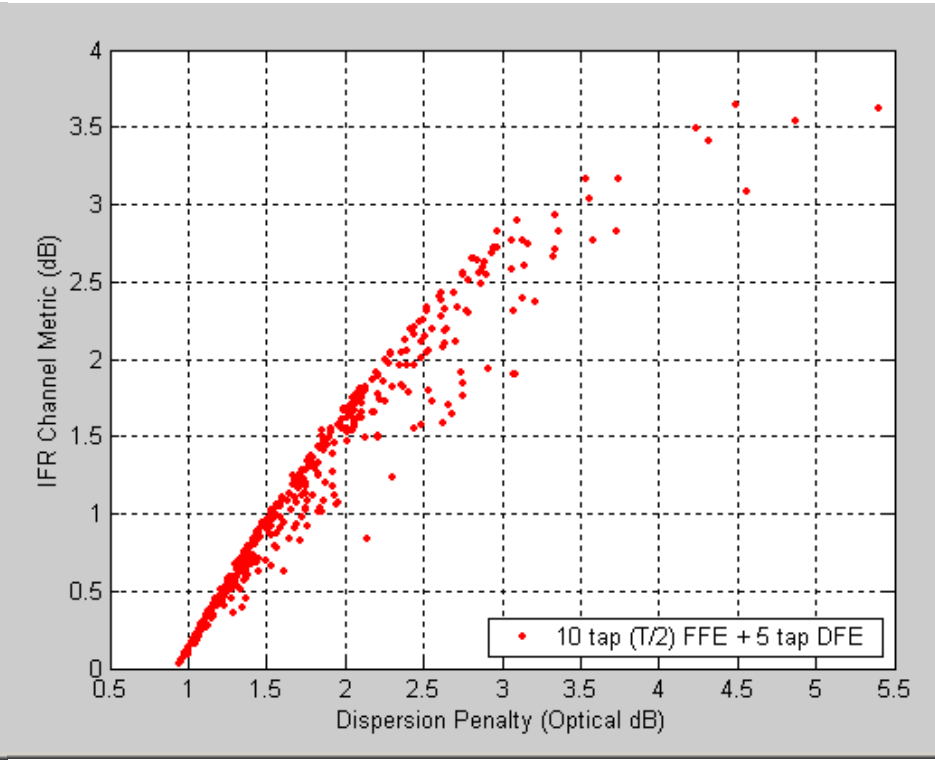


- Channel model is 220m Cambridge OSL (20um +/- 3um)
- Strong Correlation between PIE-L metric and implemented 12 tap (T/2) LE
  - PIE-L < 0.5dB spread. IFR ~ 2-3dB spread
  - PIE-L fit is linear and mapping is linear (1:1)
  - IFR fit is non linear and mapping may be launch dependent

PIE-D Channel Metric



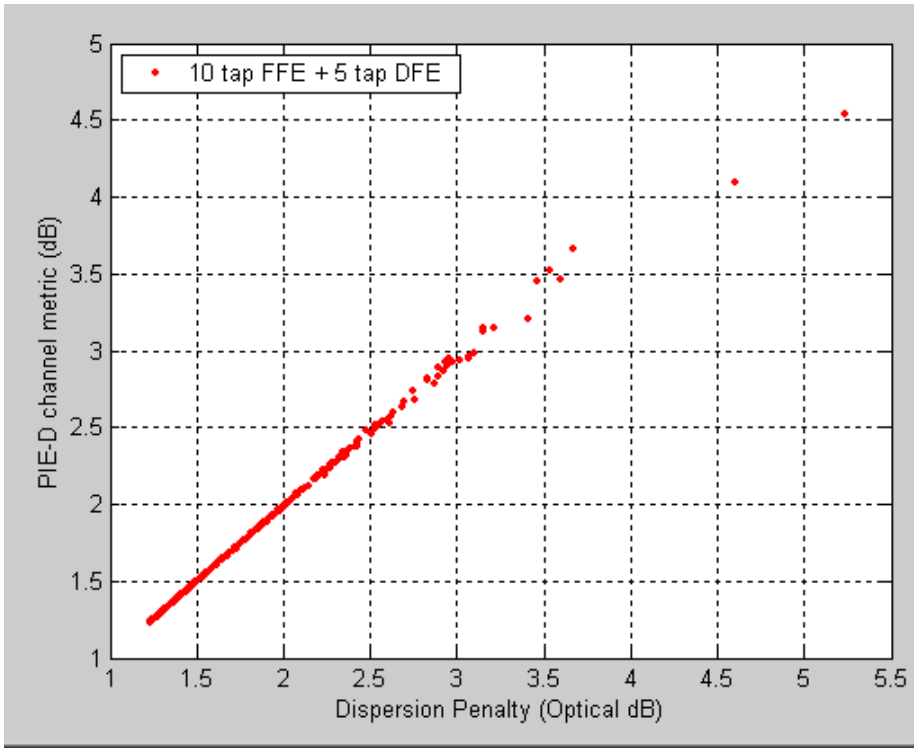
IFR Channel Metric



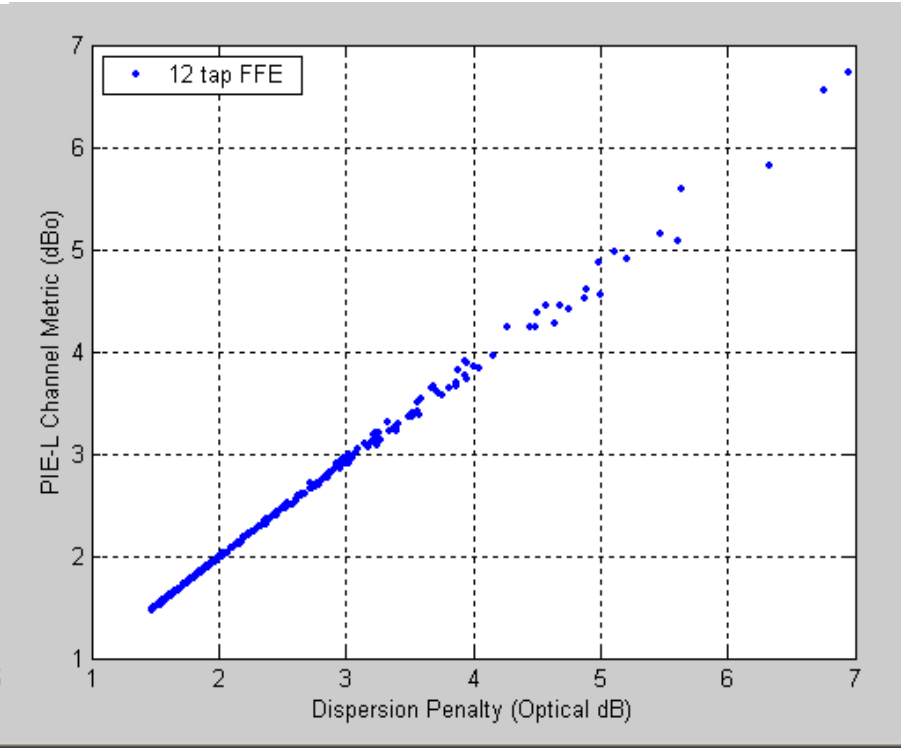
- 220m Cambridge OSL 20um +/- 3um
- Strong correlation between PIE-D metric and implemented DFE
- Weak correlation between IFR metric and implemented DFE

PIE metrics for Vortex Launch

PIE-D



PIE-L



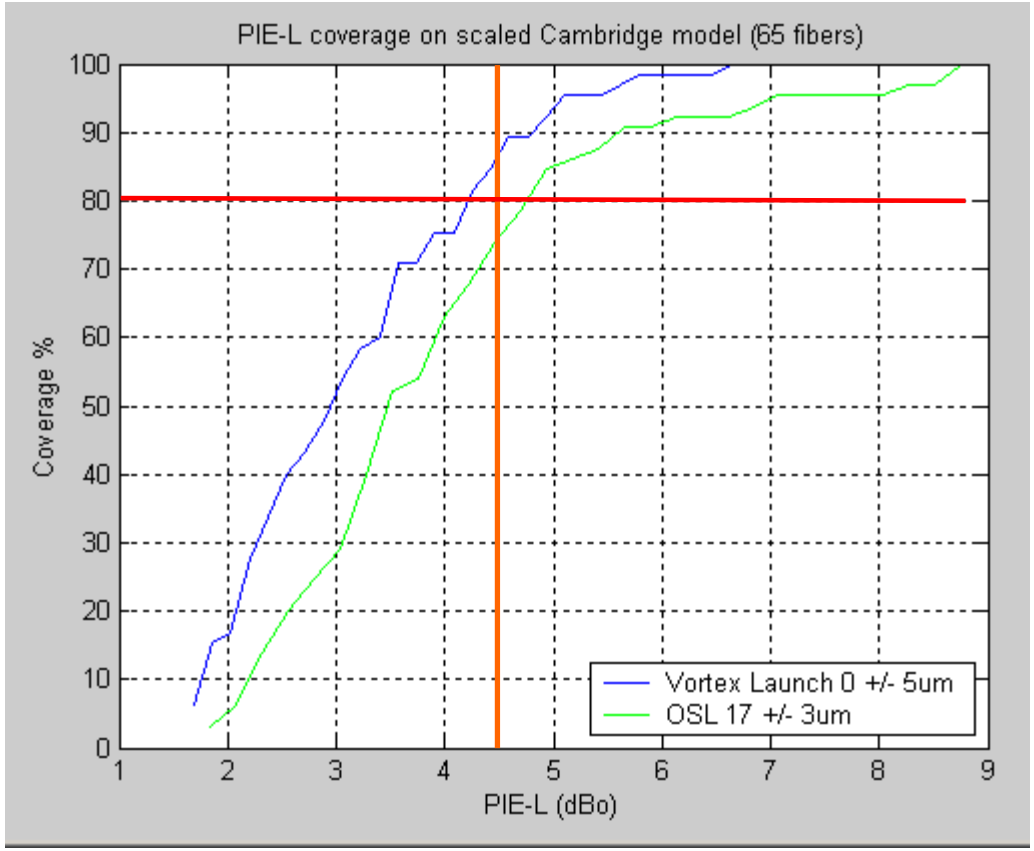
- Vortex Launch 0 +/-5um. Data provided by Jim Morris, DOC.
  - Impulse Response at 1um steps
- Strong Correlation between PIE metric and implemented finite length Equalizers

PIE vs. IFR

- Channel metrics based on ideal Equalizers show much better correlation than IFR
  - PIE-L & PIE-D have lower spread and significantly better linear fit compared to IFR
    - Theory predicts this good correlation
- Easy to come up with specific numbers for PIE-L or PIE-D from the link budget
  - Exercise in margin allocation for real EDC
- Procedure for deriving specific IFR numbers is not clear
  - IFR of 2.4dB was derived by 80% of Cambridge fibers passing IFR
  - Since correlation of IFR to dispersion penalty is weak, IFR does not guarantee yield requirements

Validating Link Budget

220m Coverage for 2 launches (PIE-L)

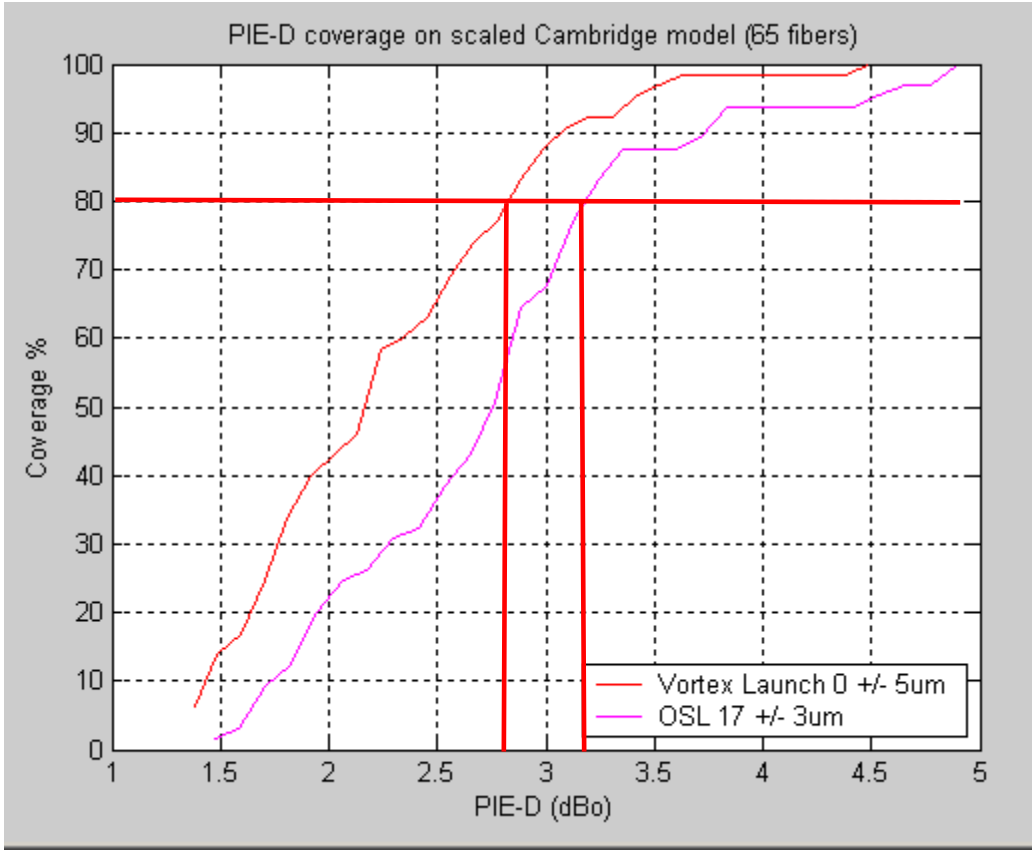


Coverage for PIE-L (4.5dB)	
Vortex +/- 5um	88%
OSL +/- 3um	73%

80% coverage	PIE-L/ Margin
Vortex +/- 5um	4.2dB/ 0.3dB
OSL +/- 3um	4.75dB/ -0.25dB

- Worst dispersion penalty for each fiber among all offsets (1um) is retained
  - Conservative definition of yield
  - Require guidance from Channel ad-hoc on number of fibers that can be dropped from this data set

220m Coverage for 2 launches (PIE-D)



Coverage for PIE-D (4.5dB)	
Vortex +/- 5um	100%
OSL +/- 3um	95%

80% coverage	PIE-D/ Margin
Vortex +/- 5um	2.8dB/ 1.7dB
OSL +/- 3um	3.2dB/ 1.3dB

Validation of Link Budget (Summary)

- Scaled 81 fiber channel model with 80% target yield
  - PIE-L
    - Vortex launch has 0.3dB margin
    - OSL launch has –0.25dB margin
  - PIE-D
    - Vortex launch has 1.7dB margin
    - OSL launch has 1.3dB margin
  - Additional 1.5dB margin is allocated for EDC implementation penalty
- EDC based 10GBASE-LRM can tradeoff various parameters to meet the required 220m yield target
  - Wide implementation space
  - Low cost

Conclusions

- PIE channel metric can predict EDC dispersion yield
- Recommend using both PIE-L & PIE-D for now
  - Both use same TP3 frequency response and are easy to compute
  - PIE-D is always lower than PIE-L
    - Margin is PIE-D vs. PIE-L can be used to tradeoff 10GBASE-LRM cost (eg. Integrated launch, Eye mask, Rx BW etc)
  - Baseline channel model adoption will provide information on whether PIE-L meets 10GBASE-LRM requirements
- Link budget was validated for OSL & vortex launches
  - Scaled Cambridge 81 fiber model
- Recommend deriving TP3 compliance parameters from PIE channel metric
- Matlab source code to compute PIE channel metric is available
  - So far 12 companies have been provided with Matlab code