Channel Metrics for EDC-based 10GBASE-LRM

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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

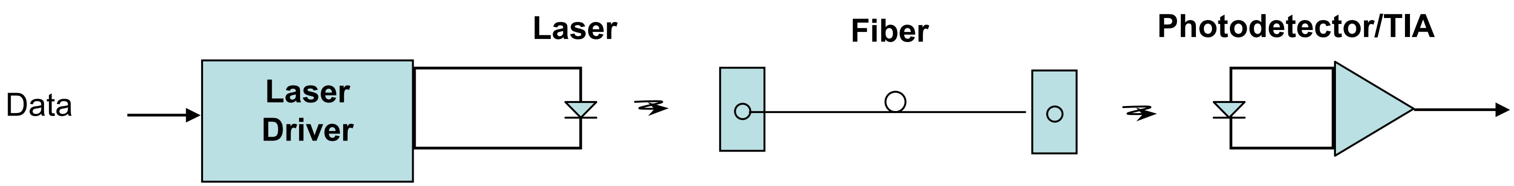
PIE – Channel Metric

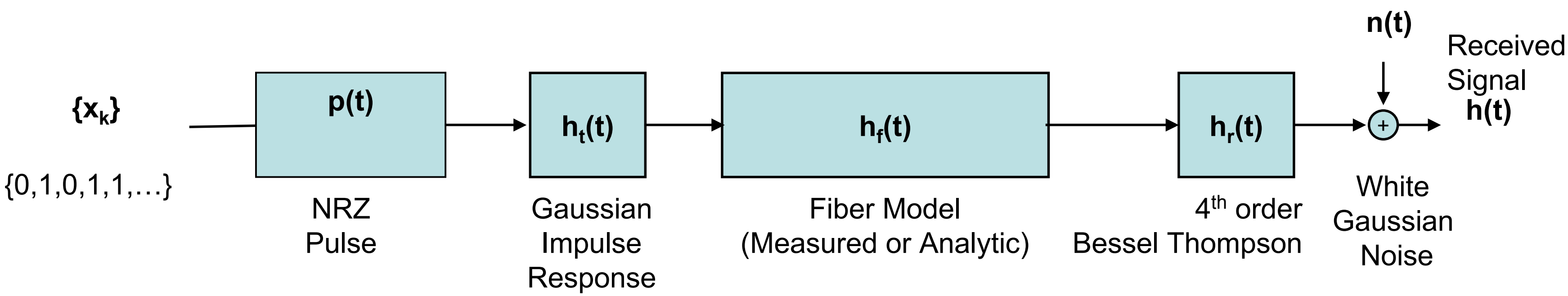
- Available Dispersion budget 6dBo (dawe_1_0504.pdf)
  - 4.5dBo penalty allocated to ideal infinite length Equalizer
  - 1.5dBo EDC implementation penalty
- PIE – Penalty of Ideal Equalizer
  - Infinite taps are assumed
  - Minimum Mean Square Error
  - Implementation independent
- 2 channel metrics 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 $10^{(-17-2*6)/10}$

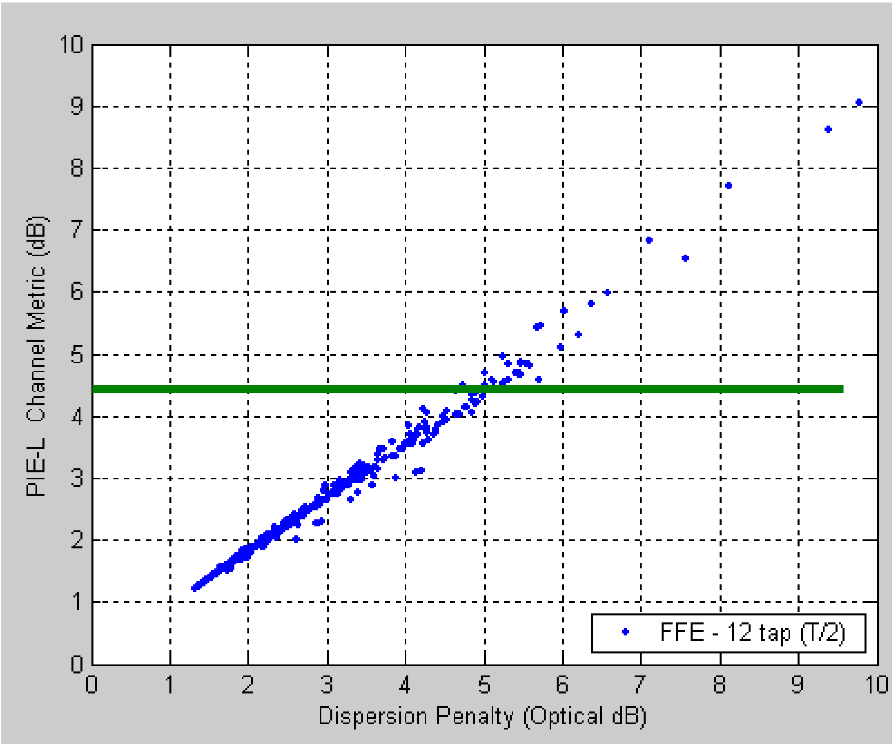
- 17dB is the required Electrical SNR for 1E-12 BER
- 6dBo is the allocated optical dispersion penalty

Dispersion penalty (dBo) of an ideal infinite length equalizer

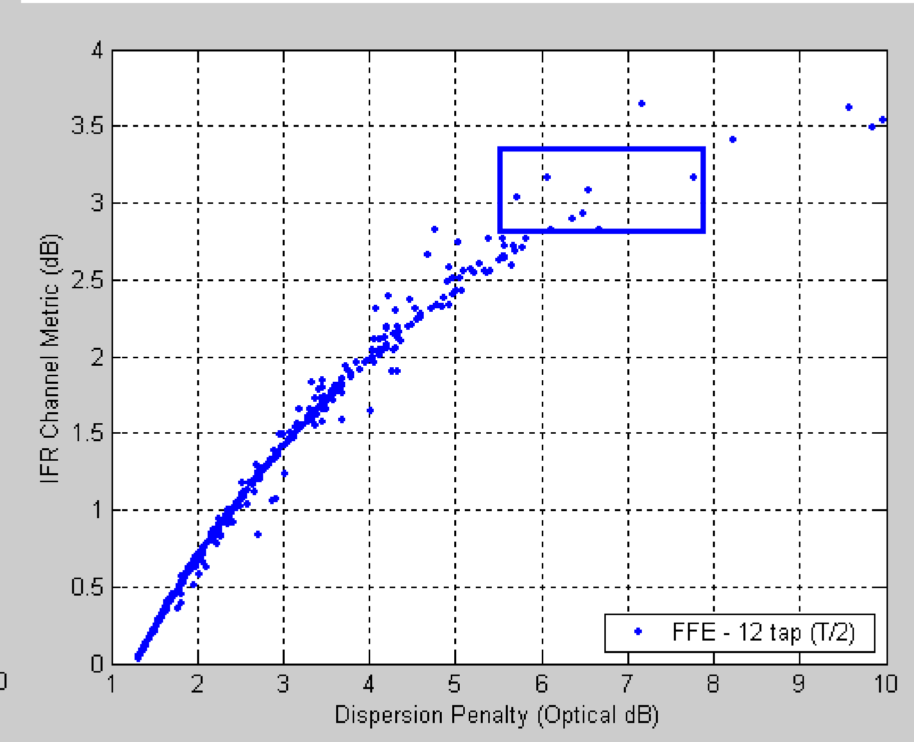
- PIE-L = 0.5*10*log10(LE)
- PIE-D = 0.5*10*log10(DFE)

Equations are derived in Lee & Messerschmitt, Chapter 10

PIE-L Channel Metric

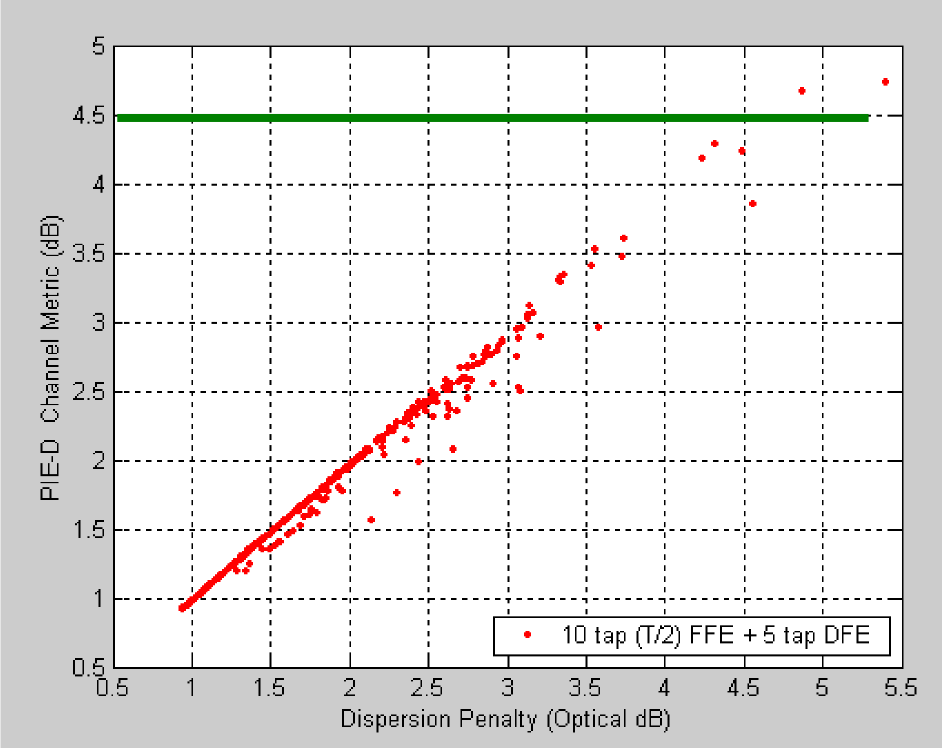


IFR Channel Metric

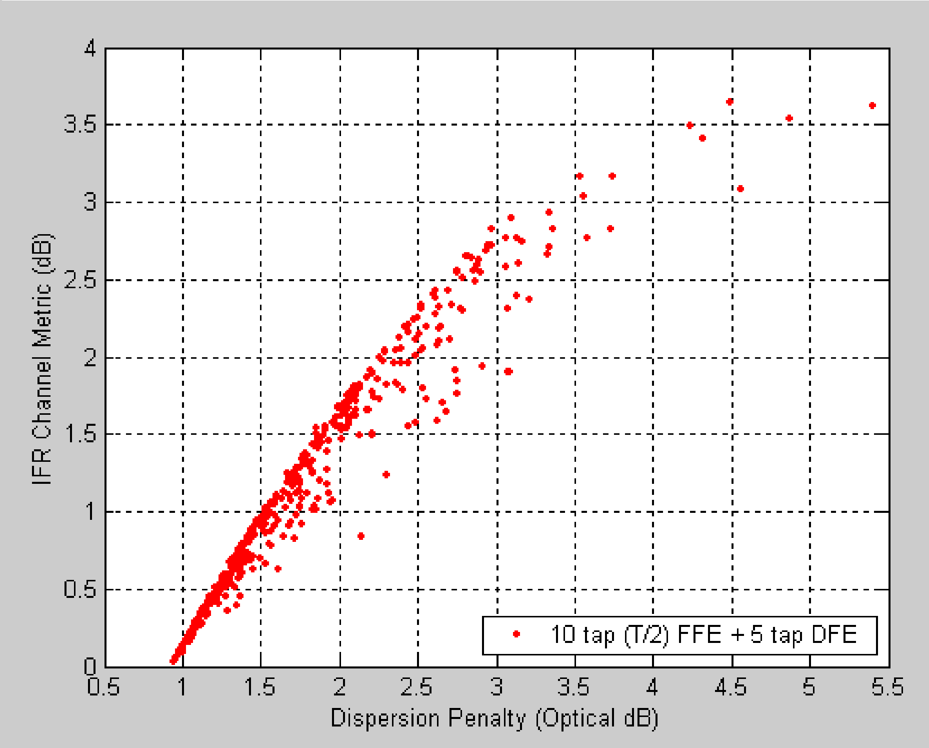


- Channel model is 220m Cambridge OSL (20um +/- 3um)
- Strong Correlation between PIE-L metric and implemented 12 tap (T/2) LE
  - PIE-L < 0.5dB spread. IFR ~ 2-3dB spread
  - PIE-L fit is linear and mapping is linear (1:1)
  - IFR fit is non linear and mapping may be launch dependent

PIE-D Channel Metric

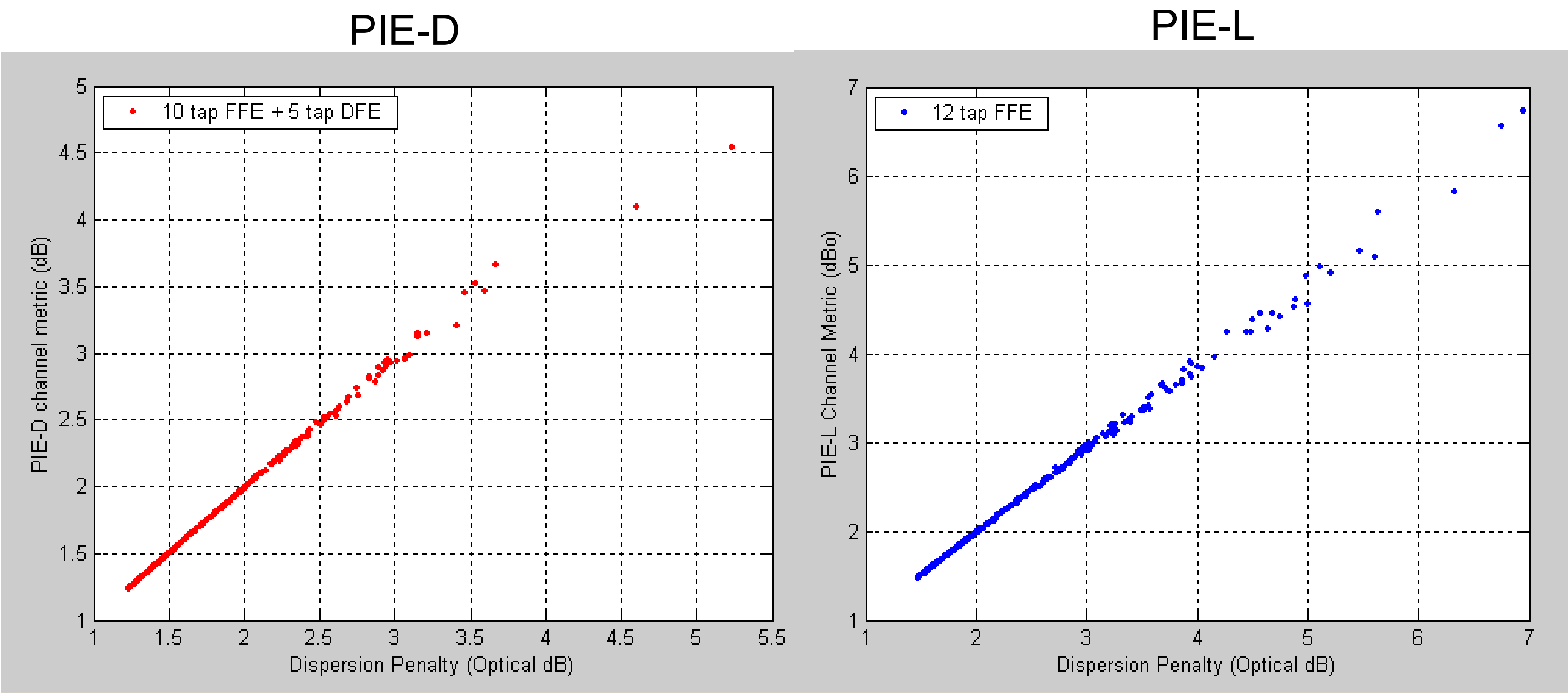


IFR Channel Metric



- 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



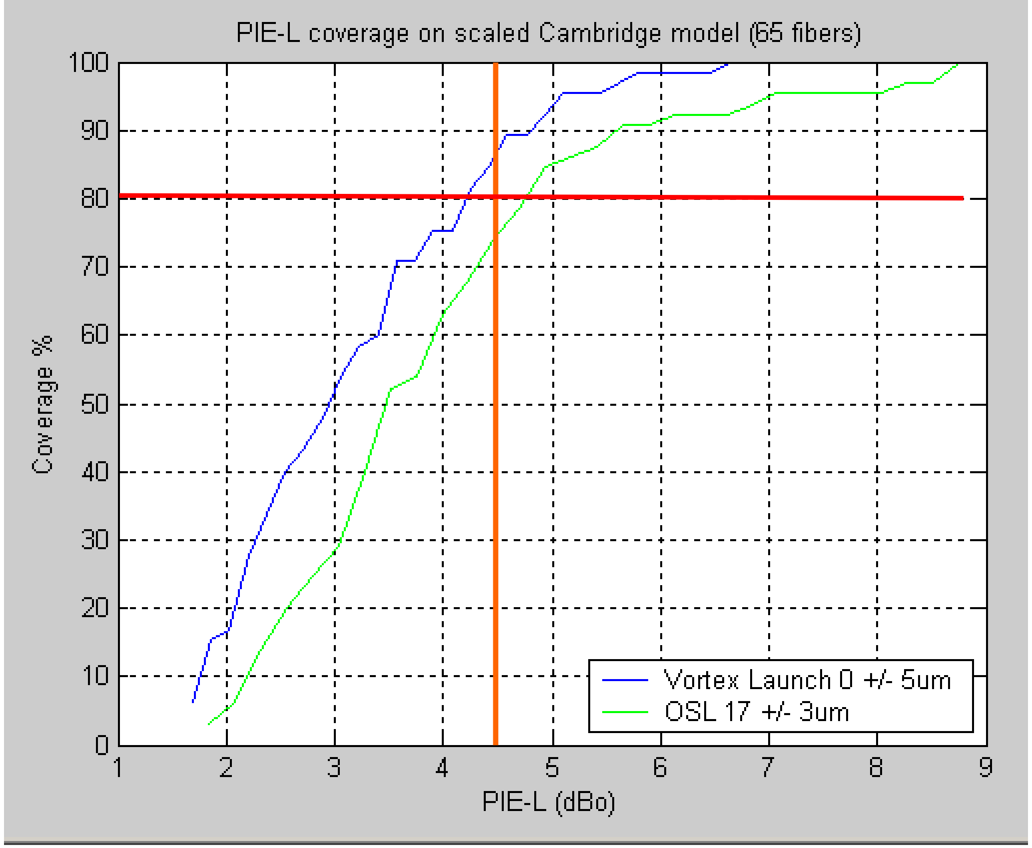
- Vortex Launch 0 +/-5um. Data provided by Jim Morris, DOC.
  - Impulse Response at 1um steps
- Strong Correlation between PIE metric and implemented finite length Equalizers

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)

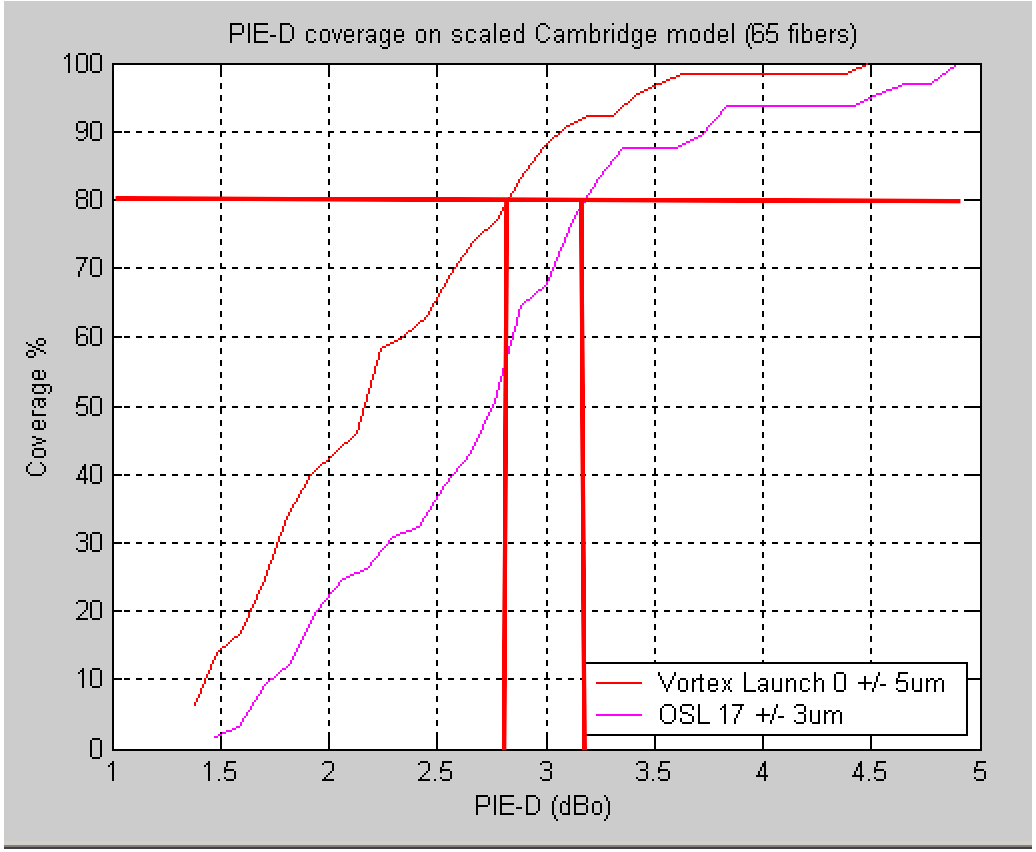


Coverage for PIE-L (4.5dB)	
Vortex +/- 5um	88%
OSL +/- 3um	73%

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