Equalizer Simulation Results for 10Gb/s MMF Channels

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Finite Length DFE Simulation

- Matlab model uses well established and documented[1] Minimum Mean Square Error analysis for finite length FFE/DFE based Rx
- MMSE results automatically account for residual ISI and noise
- T/2 spaced Equalizer are simulated
  - Allows the FFE to implement a matched filter followed by a T spaced Equalizer for optimal performance
  - Relatively insensitive to sampling phase
- Tap Coefficients $w = R^{-1} \cdot P$
  - R is the channel autocorrelation matrix of the sampled data signal
  - P is the channel cross-correlation vector
- TIA thermal noise is assumed white and gaussian
- RIN is assumed white and gaussian at the Transmitter, but spectrally shaped by the fiber and the Rx

Ref 1 - pp521-524 in "Digital Communication" by Edward Lee and David Messerschmitt

Link Parameters used in Simulation

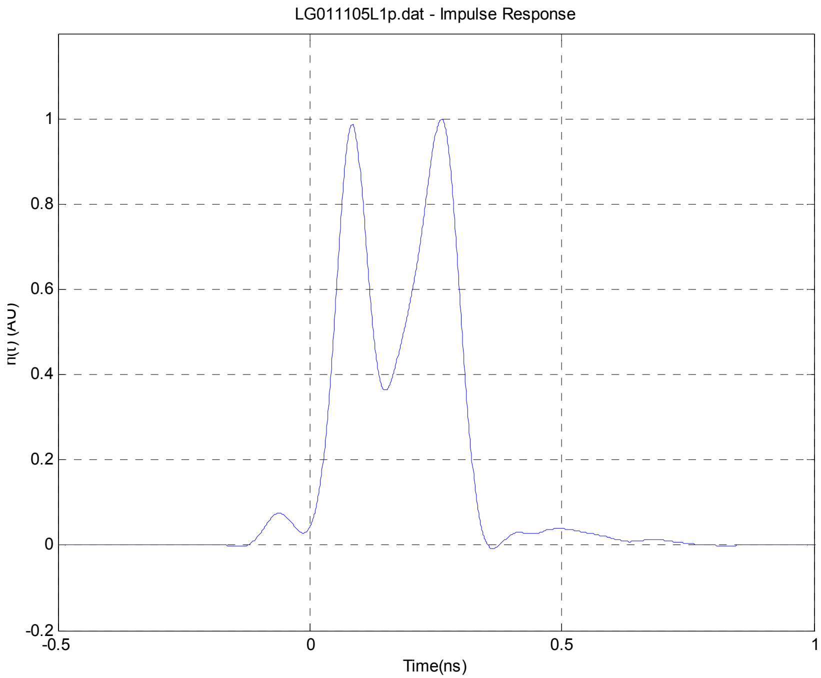
Parameter	10GBASE-L*
Tx Rise Time (20-80%)	47.1 ps
Rx Bandwidth	7.725 GHz
RIN	-128 dB/Hz
Available Power Budget	10 dB
Modal Noise and other effects	0.7 dB
Channel Insertion Loss	2.3 dB
Power Budget for Ideal[1] EDC	5.5 dB
EDC Implementation Penalty	1.5 dB
Power Budget allocated for EDC	7 dB

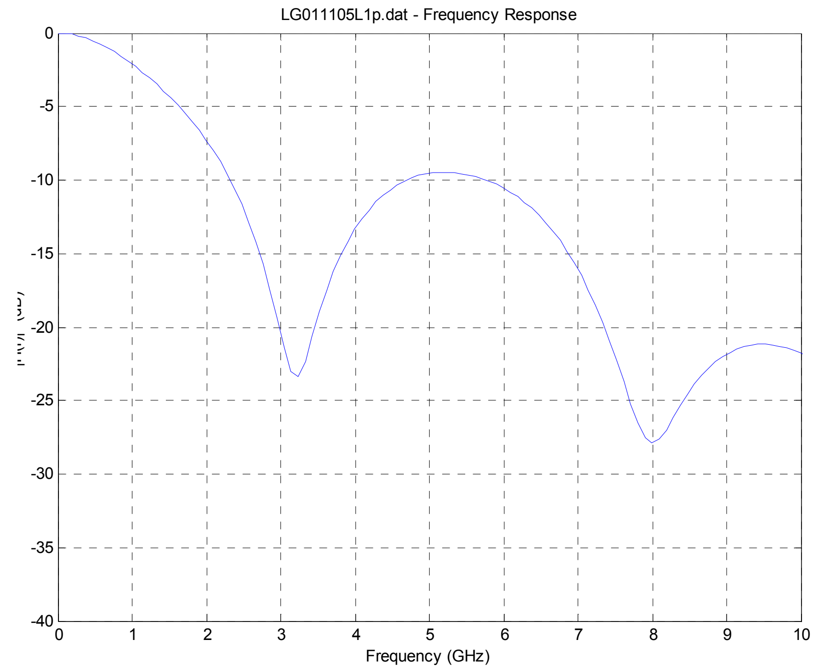
1 – Ideal EDC means infinite complexity Equalizer with perfect knowledge of the channel and perfect timing

Measured Fiber Responses

- Measured impulses from the 802.3z National Lab set of fibers
  - http://www.ieee802.org/3/z/mbi/index.html
- Fibers that had a modal bandwidth of ~500 MHz·Km were considered
- 3 fibers were chosen as representative "worst case" candidates
  1. Equal power split which causes notch in spectrum
  2. High DMD fiber and marginal modal bandwidth
  3. Single wide pulse with monotonic frequency roll-off
- Transmit pulse was deconvolved from the measured impulse response for these 3 fibers

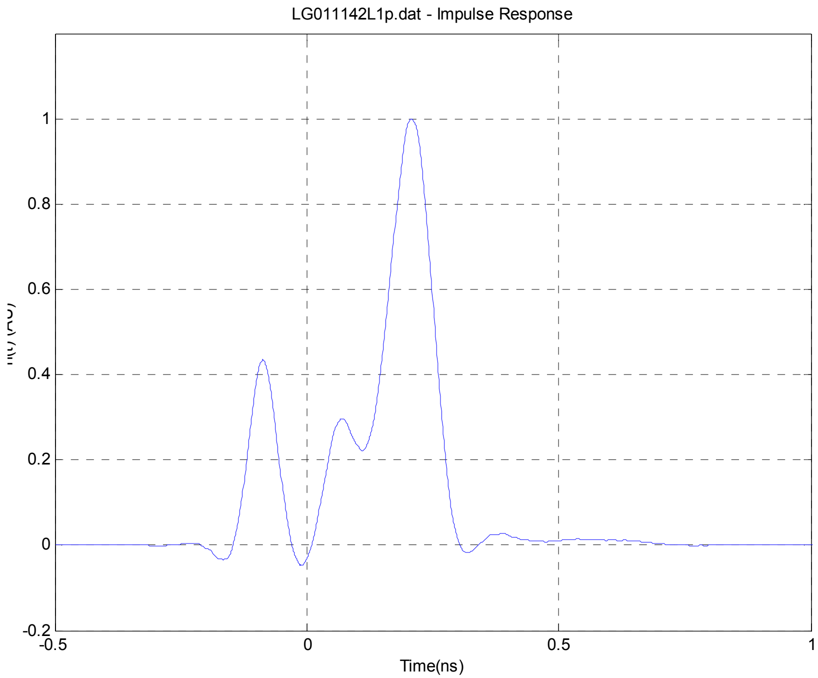
Fiber 1 - Equal Power Split

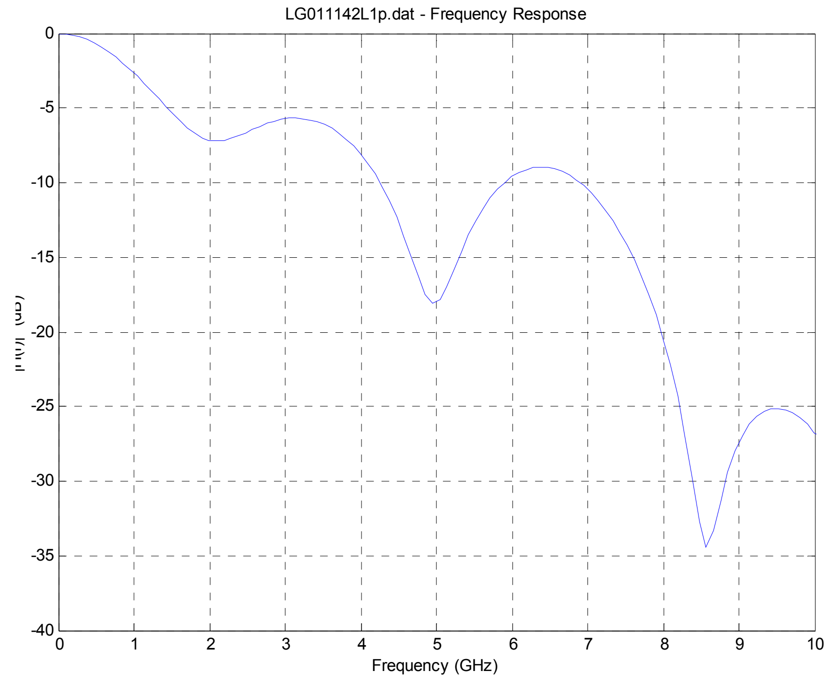




- LG011105L1p.dat - equal power split channel with a DMD of 260ps on a 457m fiber
- Scaled to 300m

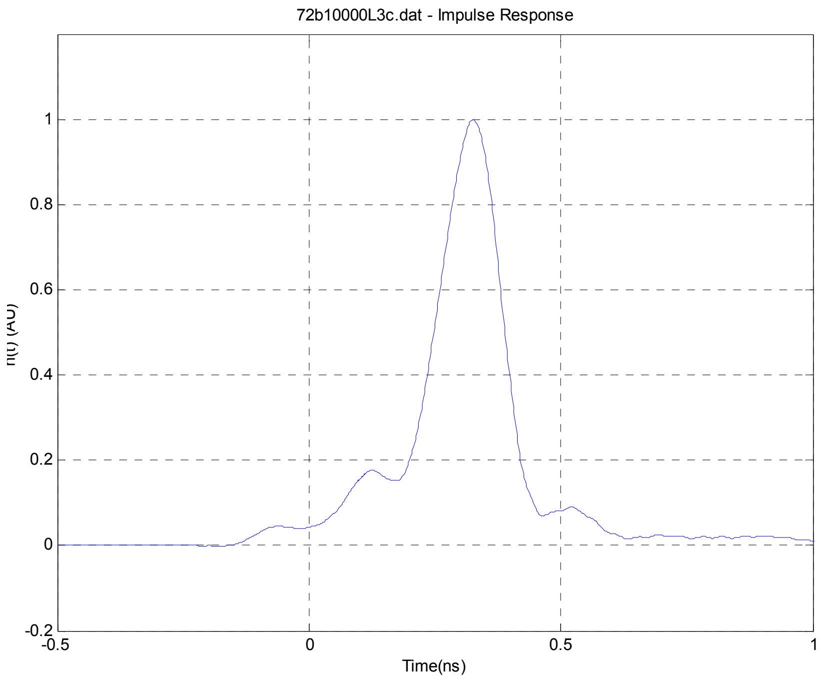
Fiber 2 - Worse DMD

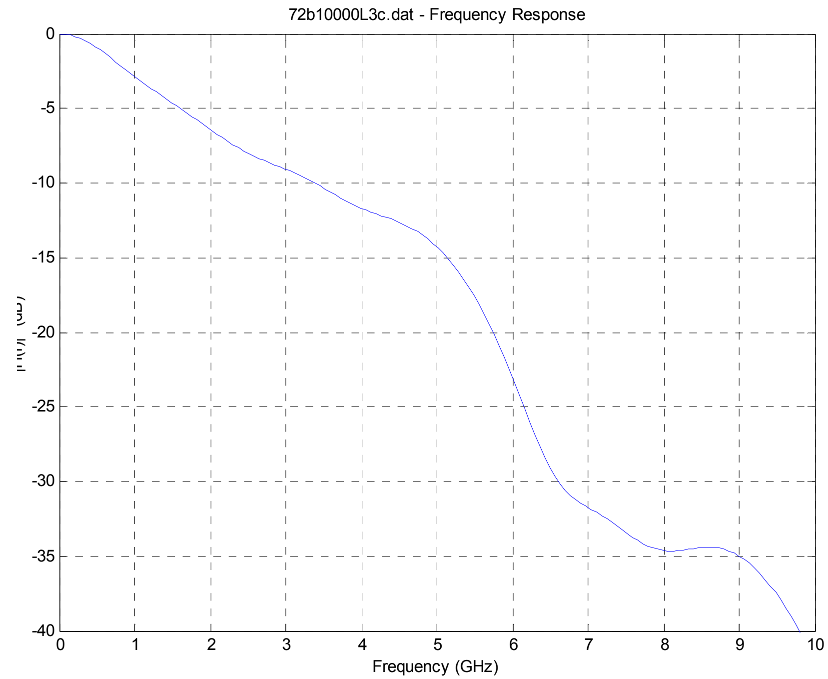




- LG011142L1p.dat - DMD of approximately 450ps on a 457m fiber
- Scaled to 300m

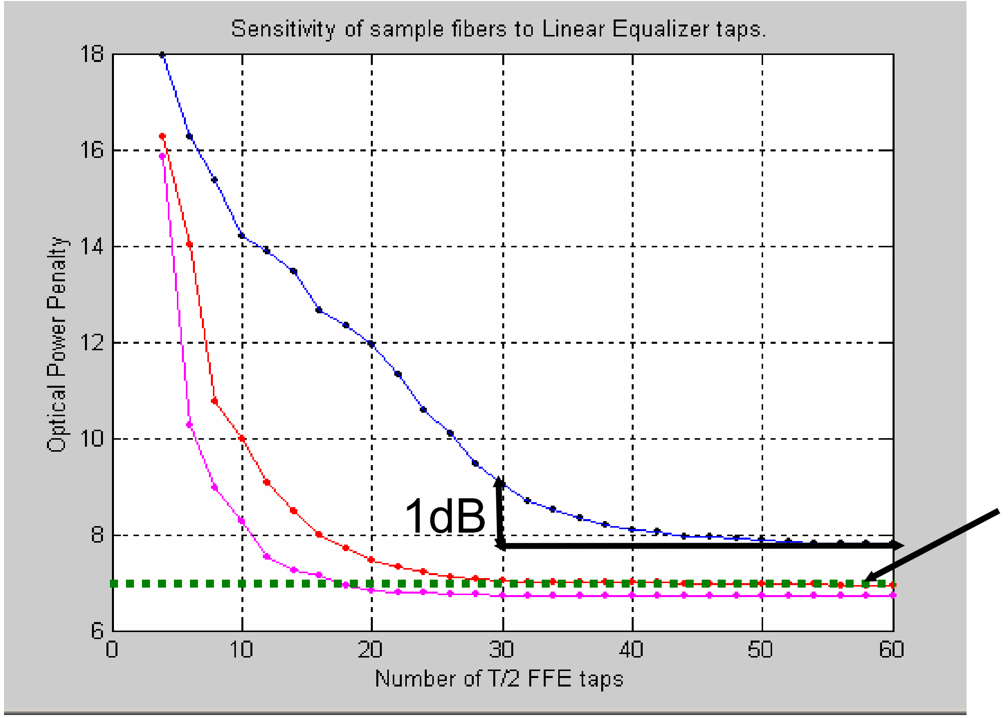
Fiber 3 - Single Pulse





- 72b10000L3c.dat - Single time-domain pulse with monotonic roll-off (no notches) in frequency domain
- Scaled to 300m

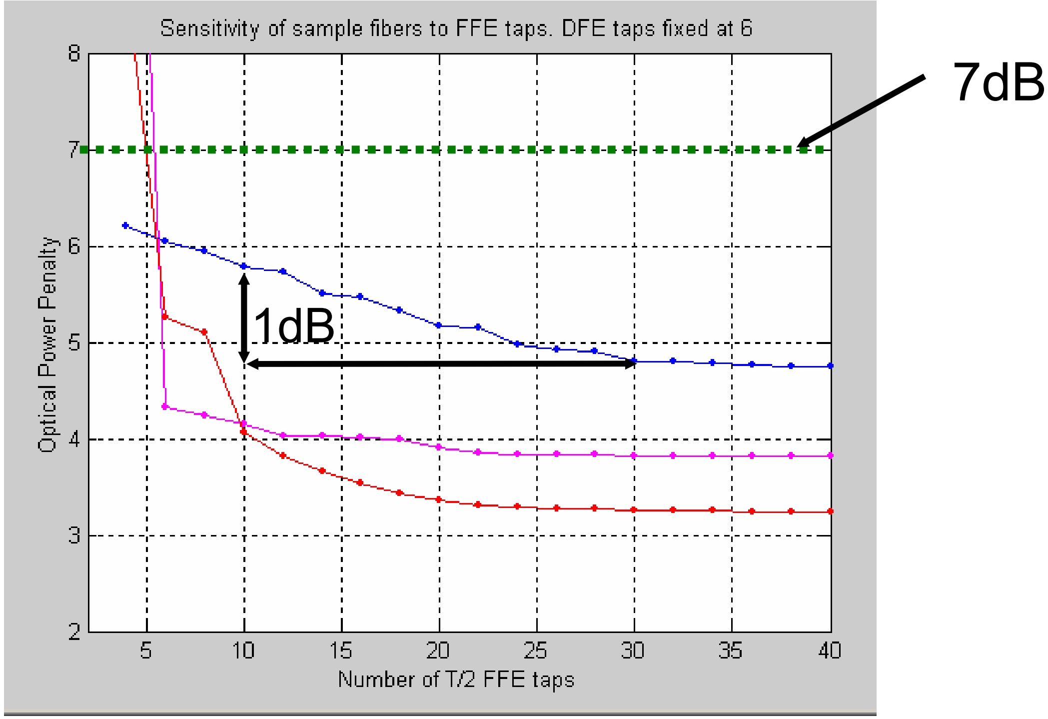
Linear Equalizer Simulation Results



- Fiber 1: High DMD
- Fiber 2: Equal Split
- Fiber 3: Wide Pulse

- On channel with deep spectral notches a relatively high # of FFE taps (>30+) are required for 1dB penalty
- The resultant power penalty is higher than the allocated budget

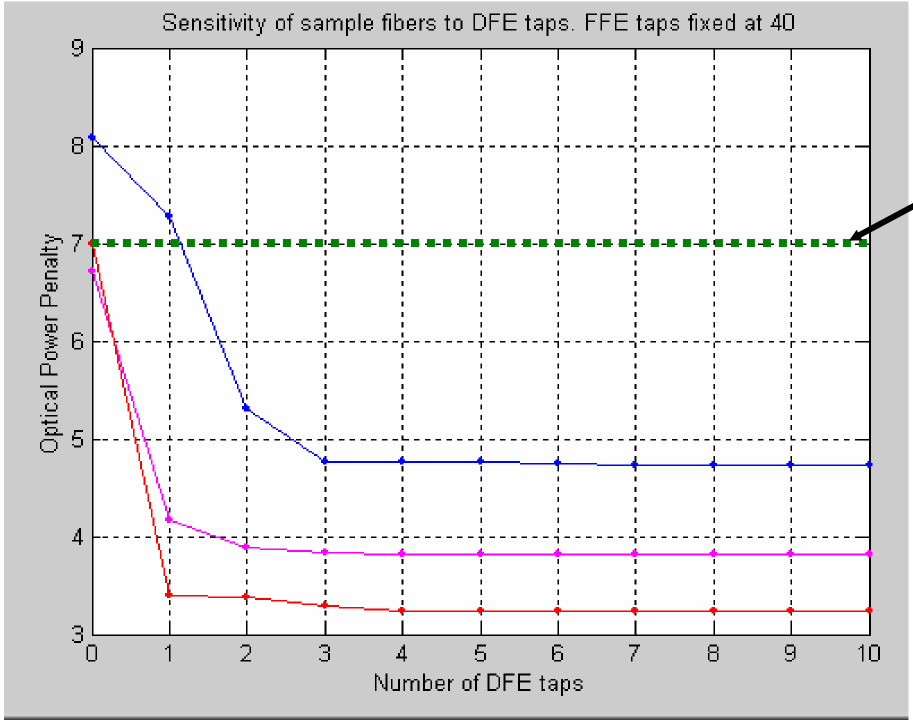
DFE Simulation Results on Sample Fibers



- Fiber 1: High DMD
- Fiber 2: Equal Split
- Fiber 3: Wide Pulse

- # DFE taps are fixed at 6 and # of FFE taps are varied
- Approximately 10-30 T/2 spaced FFE taps result in an implementation penalty of 1dB - 0dB

DFE Simulation Results on Sample Fibers

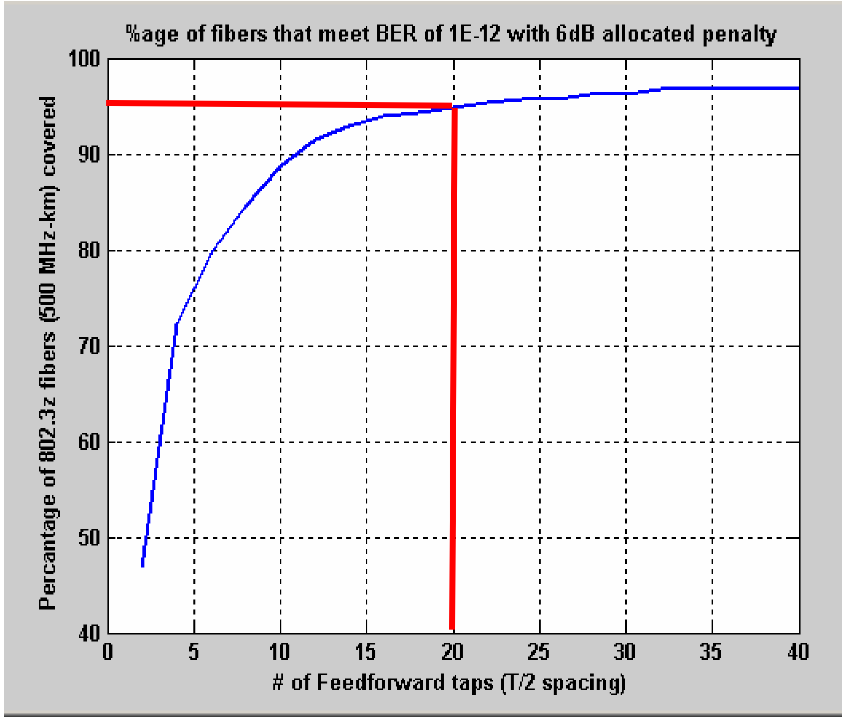


7dB

- Fiber 1: High DMD
- Fiber 2: Equal Split
- Fiber 3: Wide Pulse

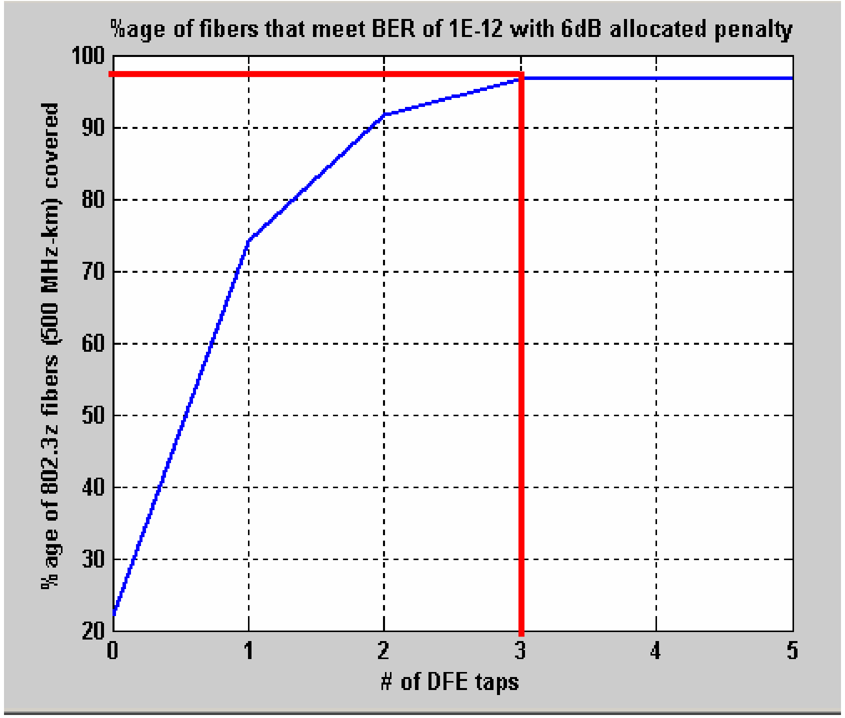
- Approximately 3 T-spaced DFE taps result in optimal performance on sample fibers
- Resulting power penalty is within allocated budget

Cumulative Coverage Results at 300m (500MHz·Km)



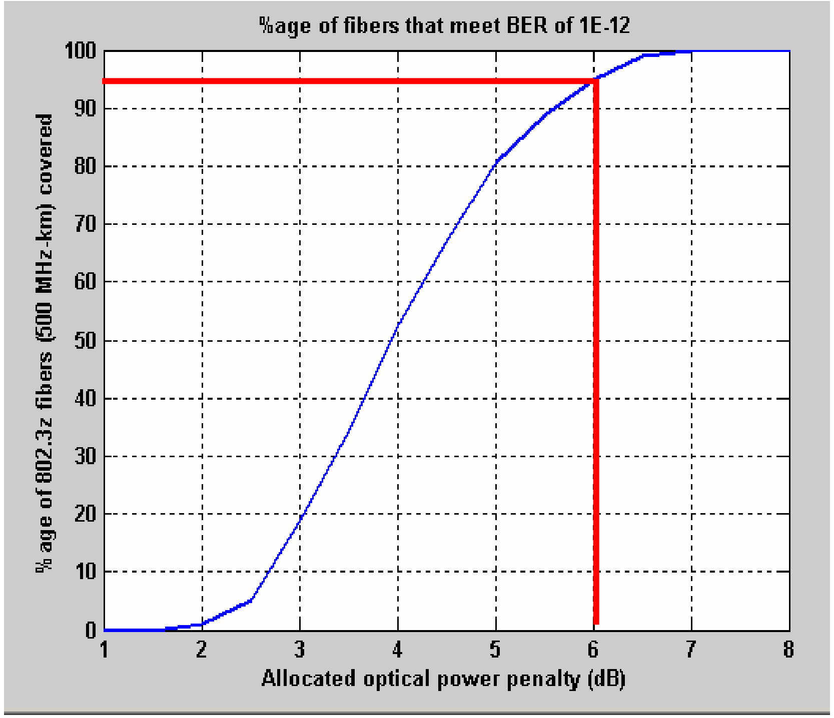
- Cumulative coverage includes all National lab fibers that meet 500MHz·Km bandwidth
- # of DFE taps fixed at asymptotic limit of 10
  - # of FFE taps are varied
- Approximately 20 (T/2) spaced FFE taps can provide 95% coverage
  - 6dB of allocated optical power budget for implemented EDC
    - 0.5dB of allocated implementation penalty for finite length Equalizer

Number of DFE Taps – Cumulative Coverage Results at 300m



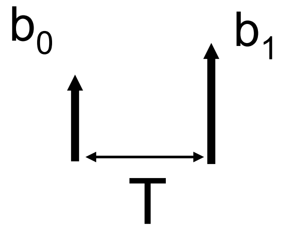
- # of (T/2 spaced) FFE taps fixed at asymptotic limit of 40 DFE taps varied
- 3 DFE taps produces ~97% coverage on measured fibers

Power Penalty vs. Coverage



- Simulated Equalizer is a 20 tap FFE (T/2) and 4 DFE taps
- 95% coverage with 6dB allocated power penalty

Time Variation Channel Model



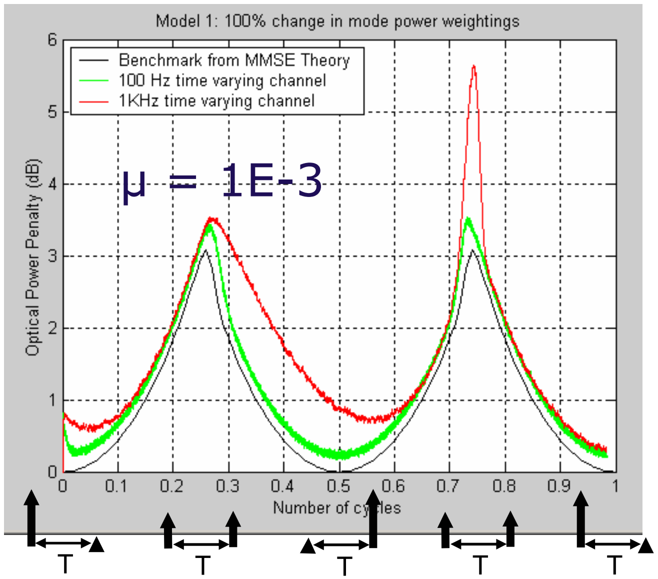
- Channel simulated is 1 bit period DMD channel
- The power distribution of the two impulses are sinusoidally varied at a rate f
  - Measurements with Center Launch indicates up to 100% changes in mode power weighting
  - Measurements with Offset Single-mode Launch typically <35% changes in mode power weighting
  - Two models were simulated
    - Model 1: Worst Case 100% change in mode power weighting
    - Model 2: ~50% change in mode power weighting
- The weights on the two dirac delta functions separated by T are
  - Model 1: $b_0 = 0.5 \,.\, (1 + \cos(2.\text{pi}.f.t))$, $b_1 = 1 - b_0$
  - Model 2: $b_0 = 0.5.(1 + 0.3 * \cos(2.\text{pi}.f.t))$, $b_1 = 1 - b_0$
- Need input from the channel modeling group on a representative time varying channel

Time Domain DFE Simulation

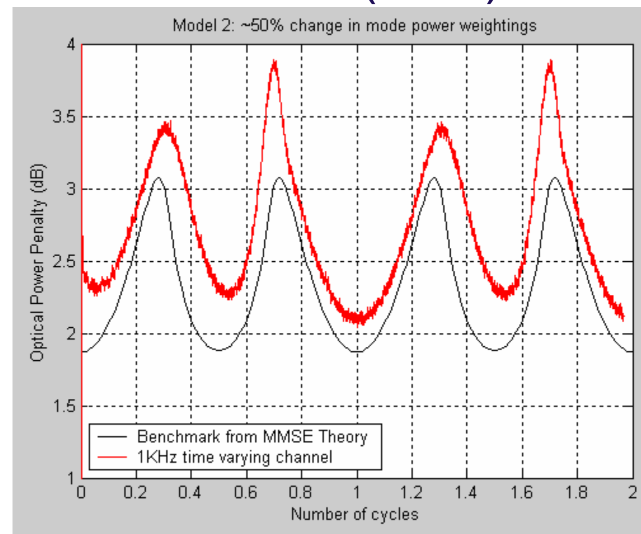
- A benchmark was established by treating each constituent impulse response as static and computing the MMSE theoretical performance
- The time domain adaptive DFE (20 tap FFE (T/2) and 5 tap DFE) was updated at full rate by a decision directed LMS adaptation algorithm
- The adaptation step size μ determines speed of adaptation
  - For stability with LMS adaptation $\mu << 2 / \lambda_{max}$.
    - λ_{max} the maximum eigenvalue of the autocorrelation matrix R was computed to be ~2
  - μ should be small to keep excess MSE small
  - Sub sampled implementations of LMS "effectively" decrease the step size μ

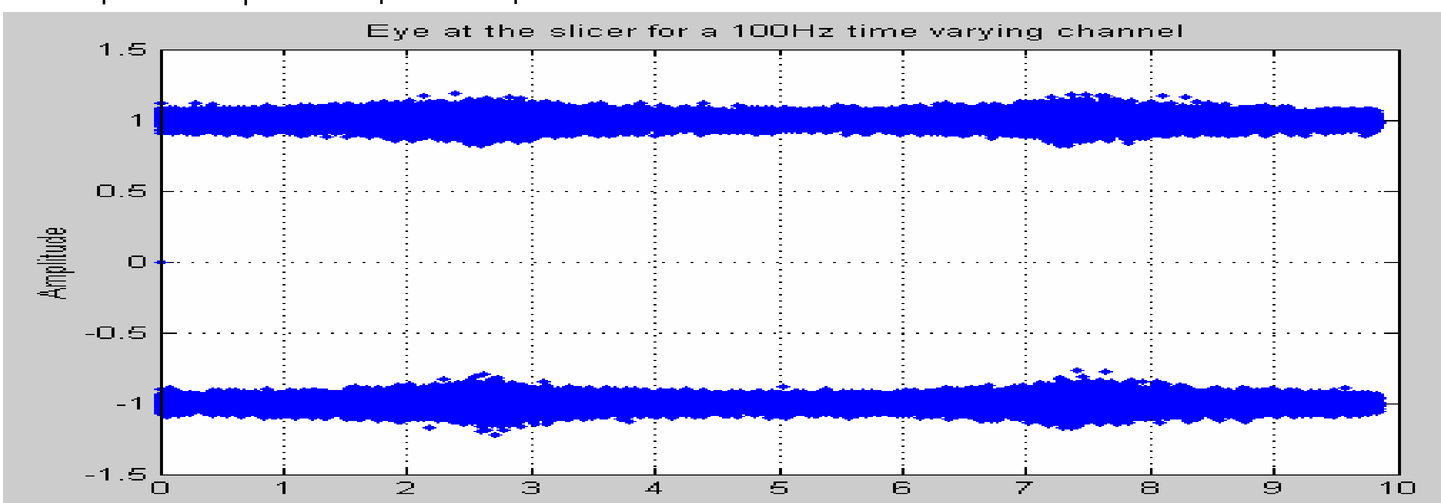
DFE Tracking Performance

Model 1 (100%)



Model 2 (50%)

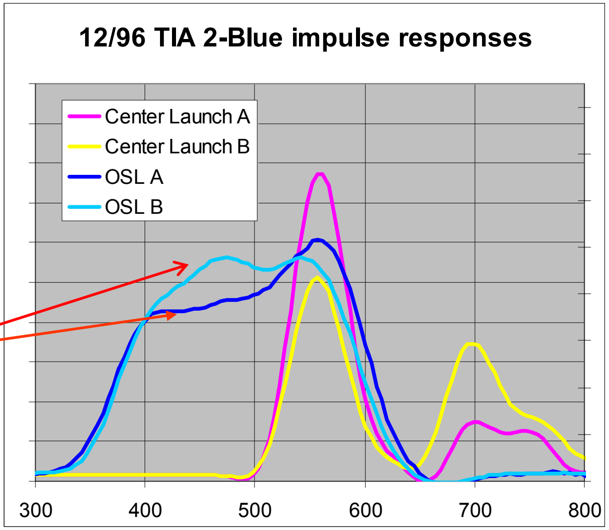




DFE Tracking Performance Summary

LMS μ = 1E-3	Implementation Penalty (dB)	
	100Hz	1 KHz
Model 1 (100% Power change)	0.5 dB	2.5 dB
Model 2 (~50% Power change)		0.75 dB

~20% change
in example IPR



Measurements indicate <35% change in mode power weightings with OSL[1]

Ref 1: J. King, "Effect of Launch Conditions on Bandwidth of TIA 12-96 Round Robin Fibers"

Conclusions

- Finite length FFE and DFE can come within 0.5dB of ideal, infinite tap equalizer for these channels
- A Linear Equalizer cannot be accommodated within a 7dB allocated budget for EDC
- A realizable set of FFE and DFE taps can be accommodated within a 7dB allocated budget for EDC
- ~20 T/2 FFE taps & 4 DFE tap combination covers 95% of measured fibers at 300m for BW > 500MHz-km
- 100Hz – 1KHz dynamic tracking performance can be achieved within the allocated implementation penalty
  - Additional input from the channel modeling group required for a representative time varying channel model