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# PIE-D Analysis of 1998 FDDI Fibers

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# Objectives

- Help establish validation procedures for 802.3aq LRM

1) Determine PIE-D metrics for a large set of legacy fiber data to compare to fiber modeling efforts and determine thresholds required for compliance testing.

2) Assess the impact of polarization variation on PIE-D for FDDI fibers with kinks (i.e. broad impulse responses in OSL region)

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# Large-Scale Study of 1998 Vintage FDDI Fibers

# Legacy Fiber Set Description

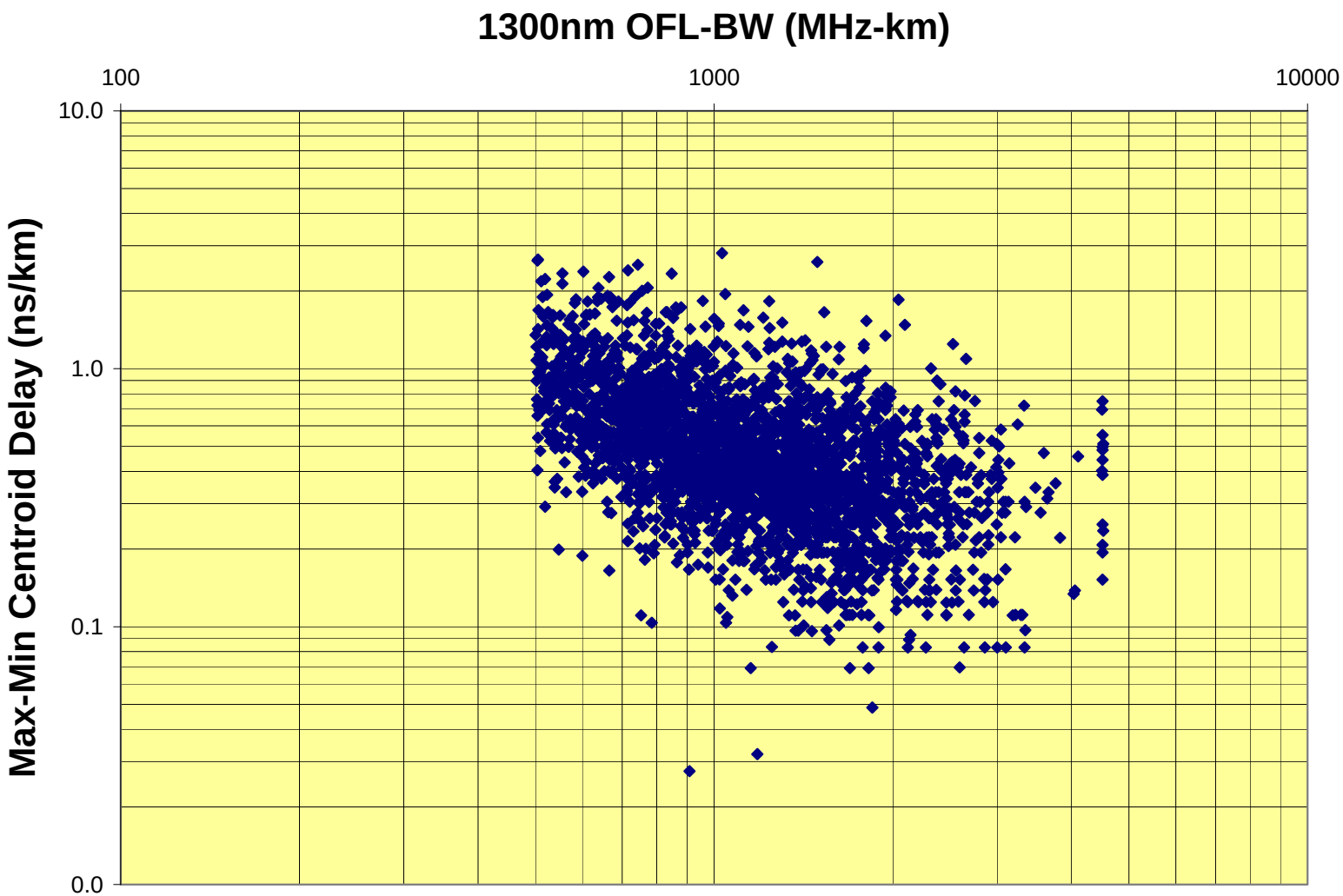
- For the fibers studied:
  - All fibers are >500 MHz-km, FDDI-compliant fibers
  - Max-min centroid delays range from < 0.1 ns/km to 2.8 ns/km
  - Includes **ALL** fibers manufactured from March to June of 1998
  - 1998 represents approximately the mid-point for cumulative FDDI deployment

- DMD data set restrictions
  - Length > 5km, insures sub-50ps resolution without deconvolution
  - Low noise
  - Free from spurious features
  - Free of large asymmetries
  - Retain 1423 fibers

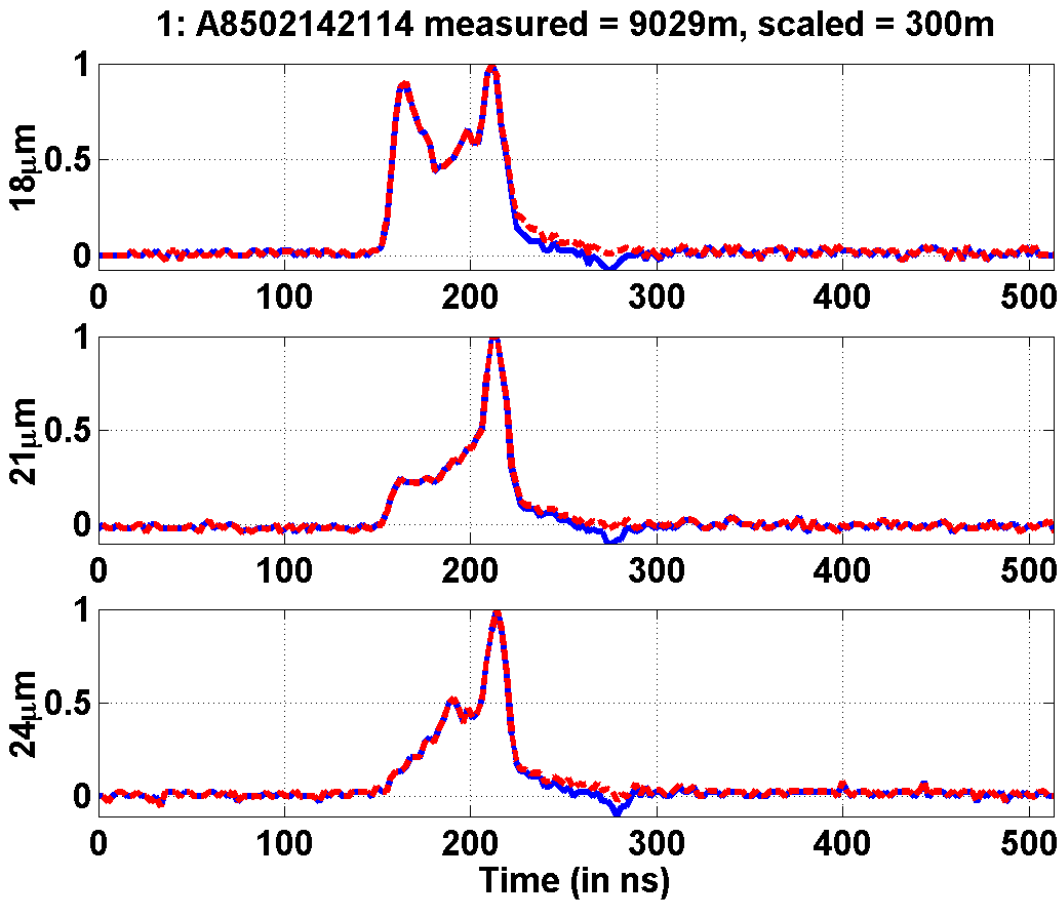
# Methodology for Processing DMD Data

- Clean up fiber impulse data
  - Echo cancellation:
    - Back-to-back response modeled as a sum of three pure Dirac-delta functions
    - h(0) = 1; h(23) = -0.02; h(25) = -0.07; Sampling period = 0.25ns
  - Eliminate DC shift in the response
  - Scale to 300m of fiber length
- Compute Channel Response
  - Interpolate response to required oversampling factor (32 here)
  - Tx filter: Gaussian pulse of rise-time = 47.1ps (20%-80%)
  - Rx filter: $4^{th}$ order Bessel-Thomson filter of 3-dB BW 7.5GHz
- Clean up Channel Response
  - Zero any negative values
  - Temporal Truncation; Zero tails of temporal response when value fall 50dB below peak
- Normalize Channel response to unity area
- Zero-pad to integer number of bit periods

# Basic Properties of the Data Set



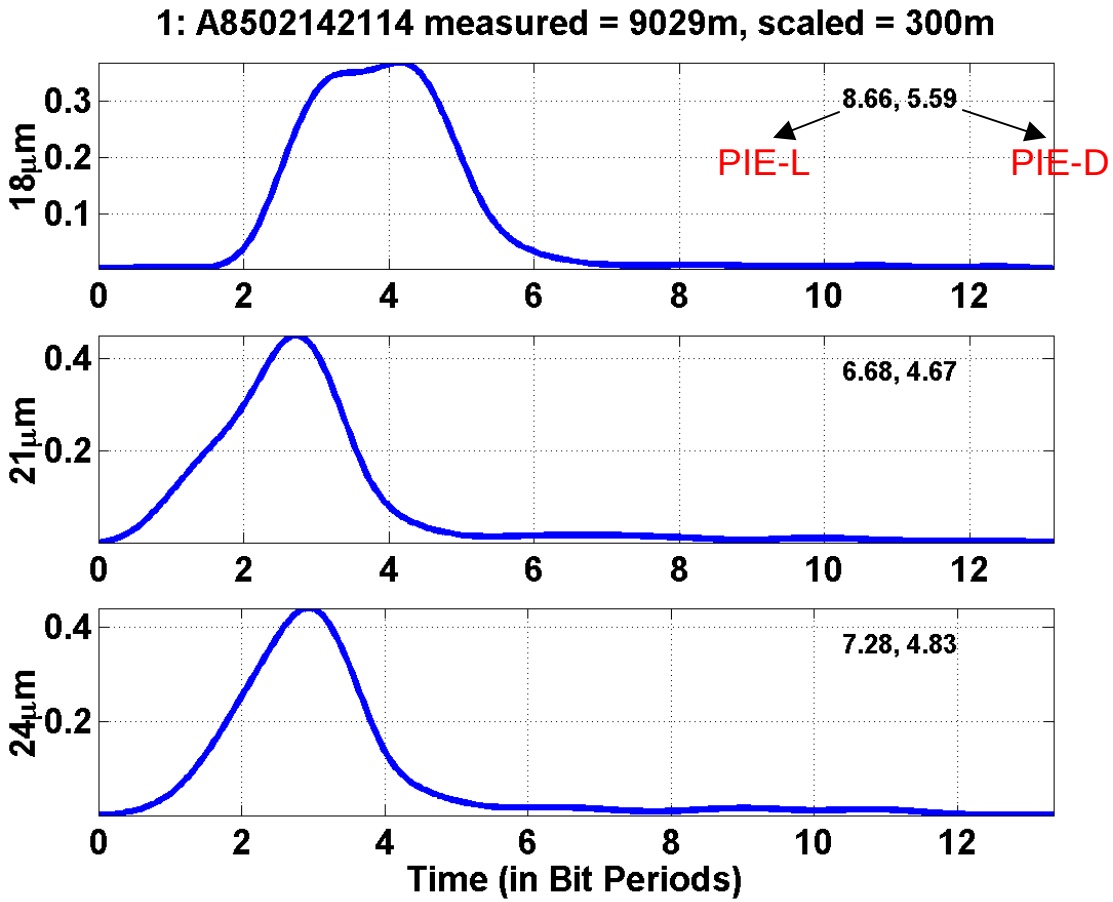
# Fiber A8502142114 : after echo cancellation




- Blue: original measured response
- Red: response after echo cancellation

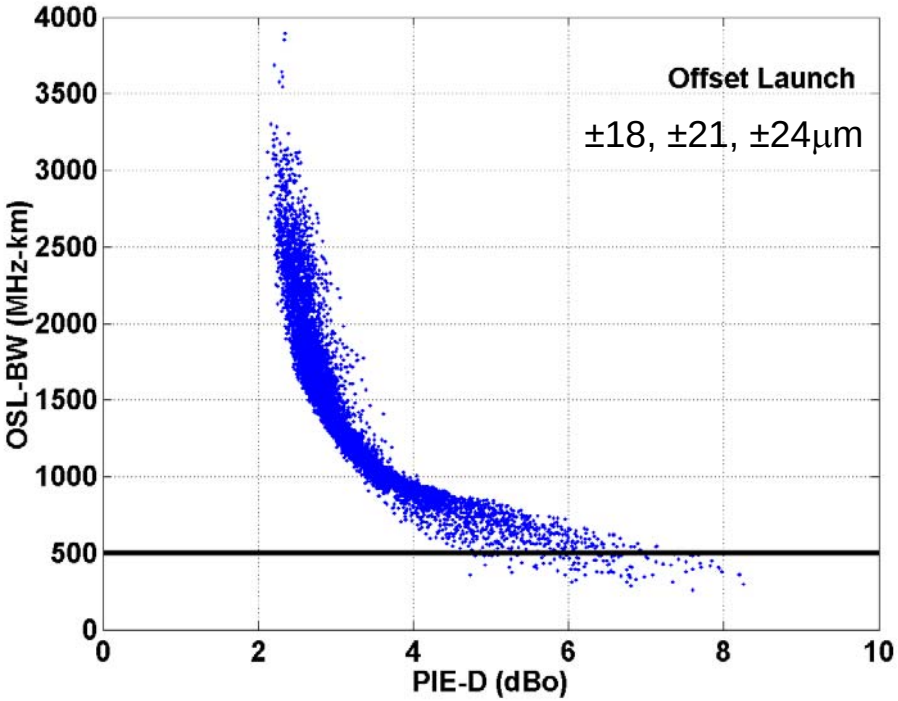
- Ringing effect reduced significantly:
  - Resulting gradient is smooth, variations are of the order of the noise variance
- Three impulse model of the back-to-back response works well

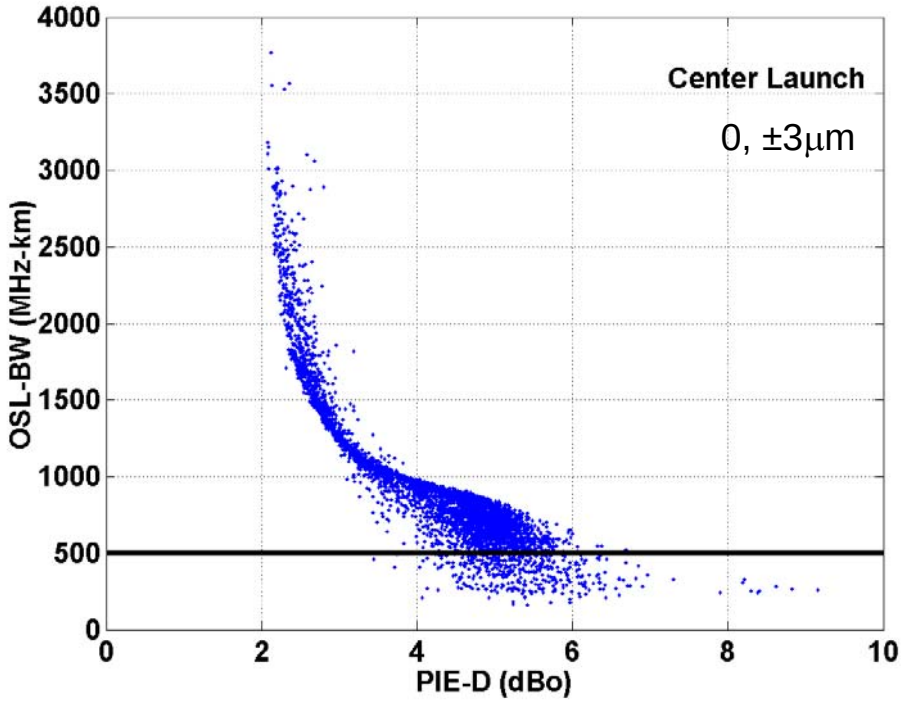
# Example A8502142114 : end-to-end responses




- Inter-symbol interference spans 2-4 bit periods (in general)
- PIE-D larger than 4.5dBo

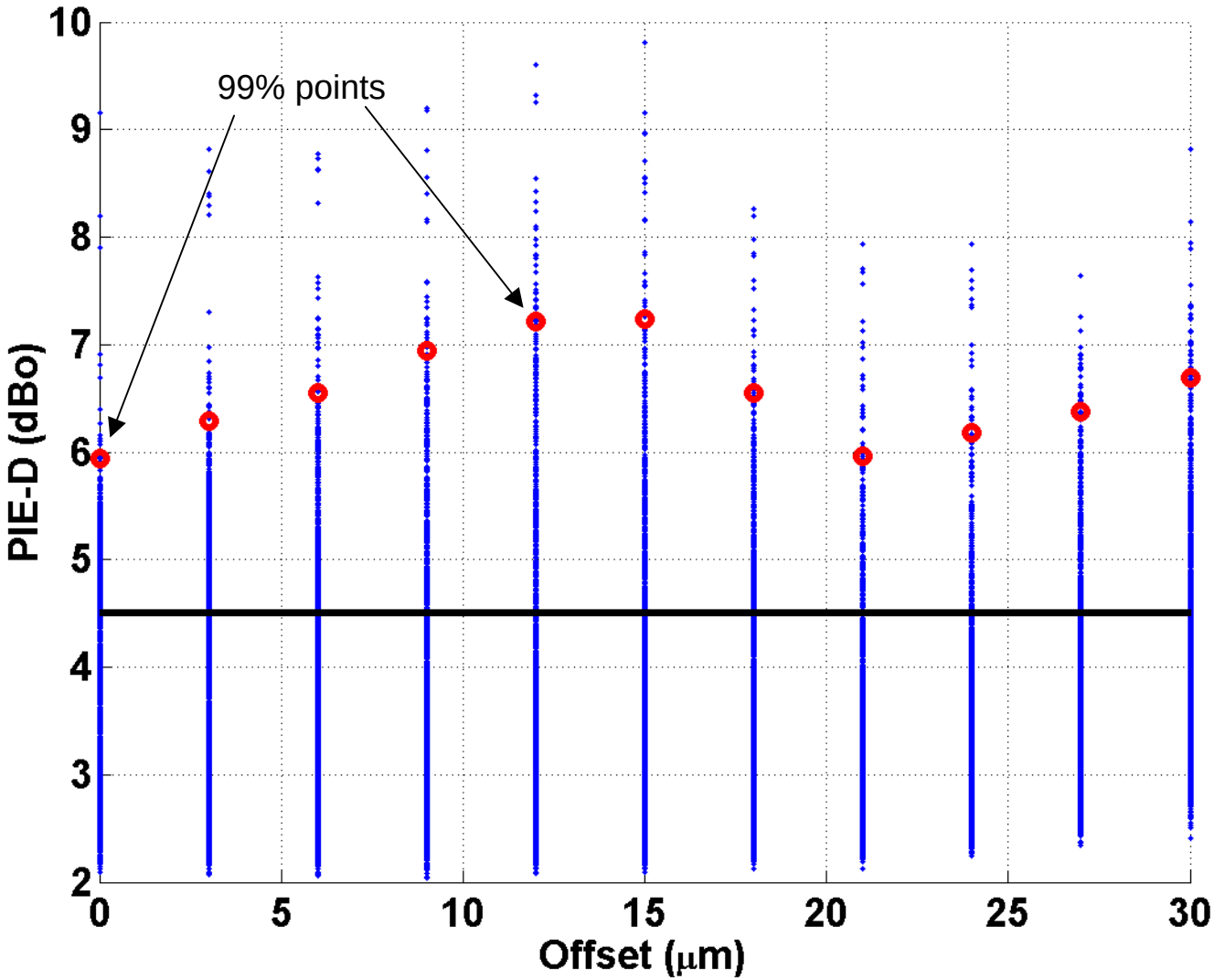
# OSL Bandwidth for Legacy Fiber Set



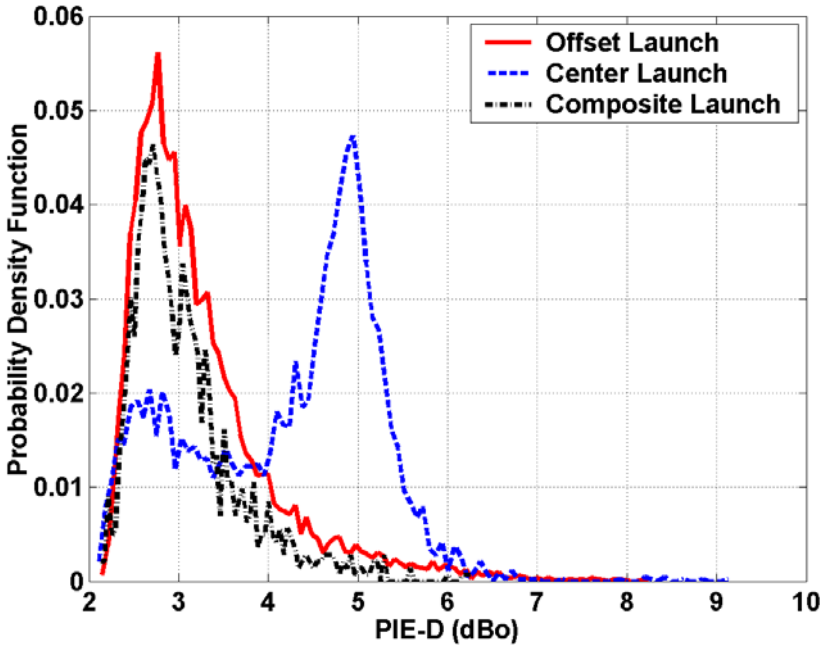



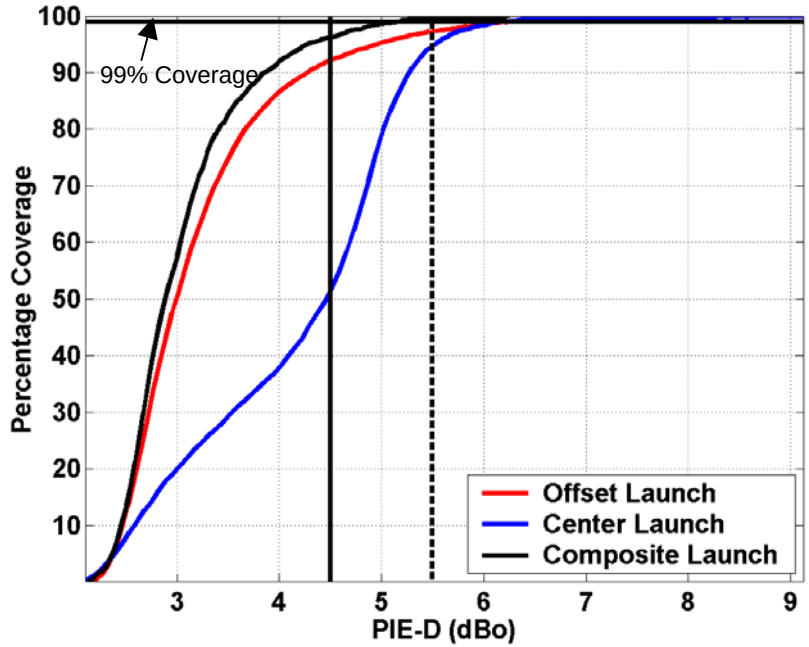

- OSL Bandwidth used to characterize the fiber set
  - Compute 3-dB bandwidth for impulse response at each offset
  - Scale to get bandwidth-distance product
  - Compute cumulative distribution in the offset launch range
- Offset Launch:
  - 1.3% of fibers have OSL-BW below 500MHz-km

# PIE-D vs. Offset for Legacy Fiber Set



# Percent Coverage




| | Offset Launch | Center Launch | Composite Launch |
|---|---|---|---|
| Offsets (μm) | ±18, ±21, ±24 | 0,±3 | Optimum launch for each fiber |
| Number of Fibers | 1423 | 1423 | 1423 |
| Probability Density Function | • single peak at ~2.5dBo<br>• asymmetric about the peak<br>• heavy tail | • peaks at ~2.5dBo and ~5dBo<br>• decays rapidly beyond maxima | • single peak at ~2.5dBo<br>• asymmetric about the peak<br>• heavy tail |
| Percentage Coverage at specified PIE-D limit | • 92% at 4.5dBo<br>• 97% at 5.5dBo | • 52% at 4.5dBo<br>• 95% at 5.5dBo | • 96% at 4.5dBo<br>• 99.6% at 5.5dBo |
| PIE-D for 99% coverage | 6.3dBo | 6.2dBo | 5.2dBo |

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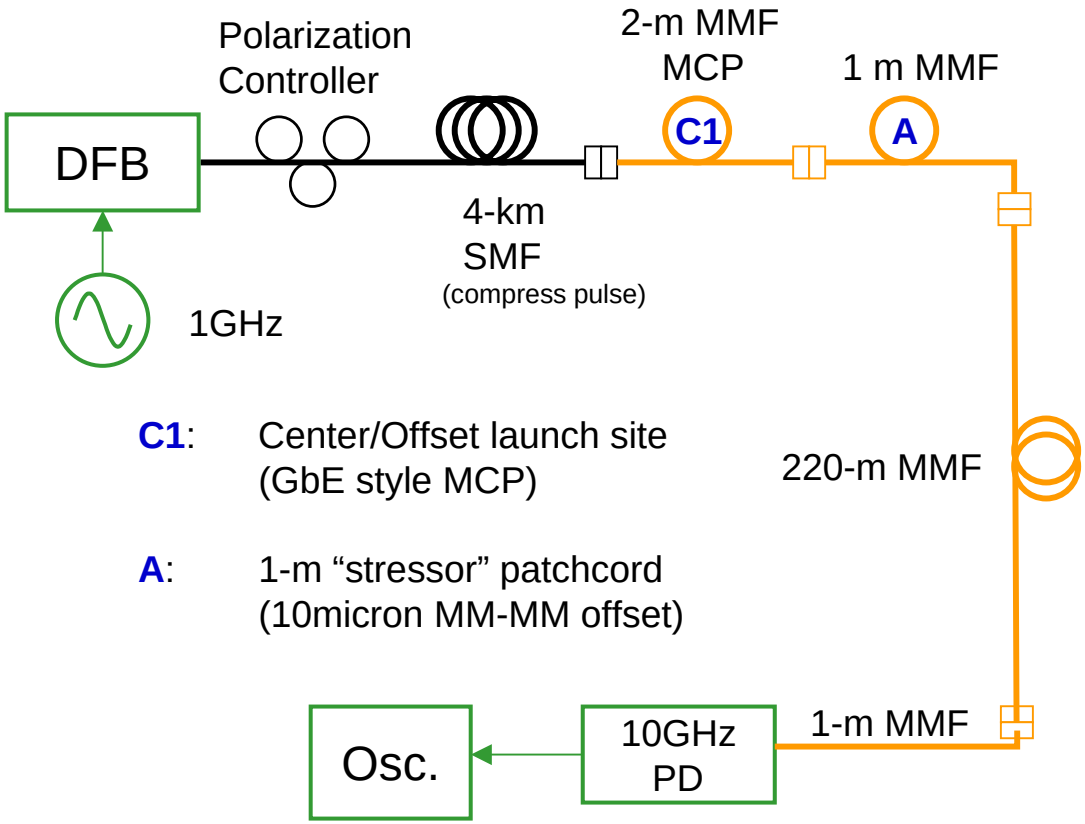
# Polarization, Connectors and PIE-D

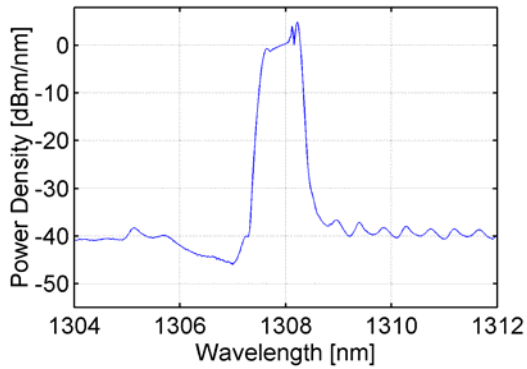
# Experimental Apparatus




**C1**: Center/Offset launch site (GbE style MCP)

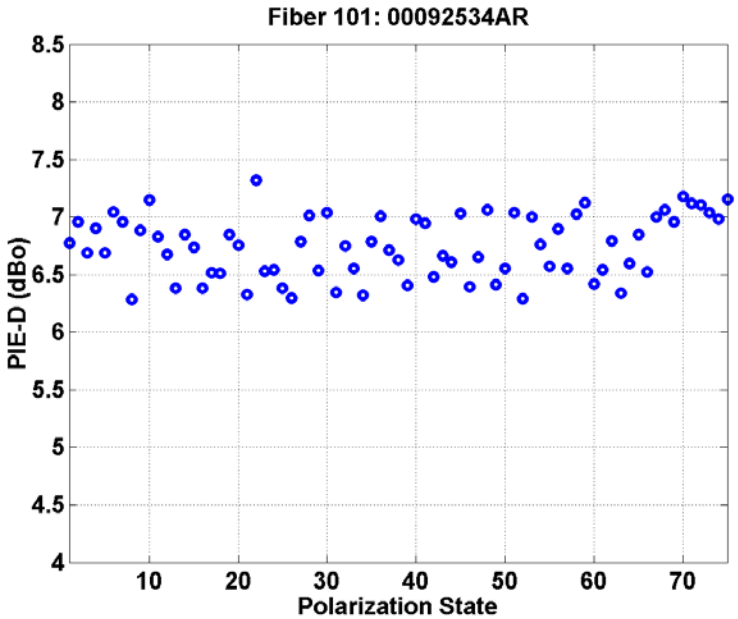
**A**: 1-m "stressor" patchcord (10micron MM-MM offset)

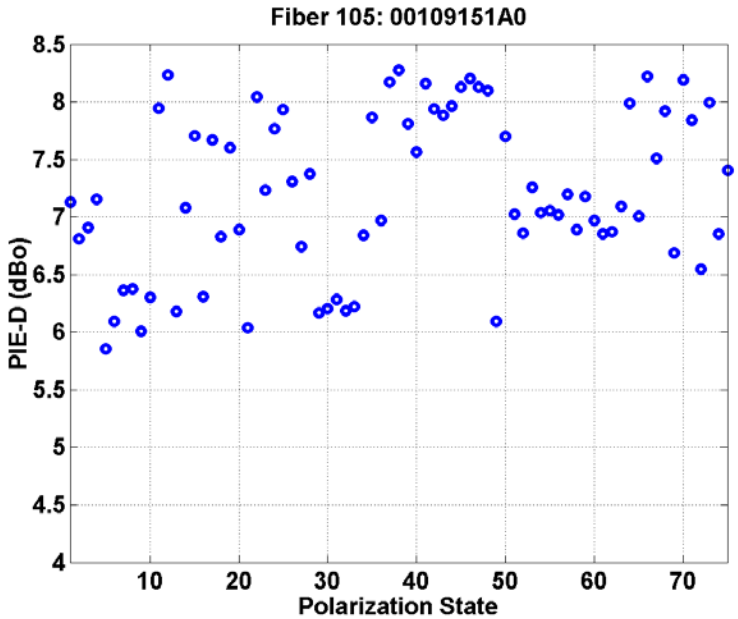
Source spectrum



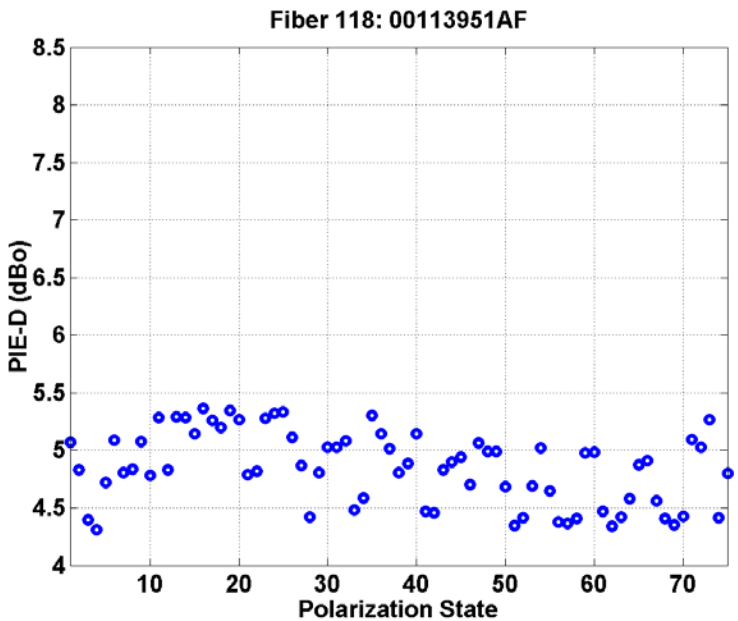

The 10micron MM-MM offset splice **A** is intended to represent the MPD effects corresponding to two, worst-case 7-micron offset connectors. A single 9-micron offset would have been better, but the 10-micron was readily available.

# Spread in PIE-D due to polarization variation



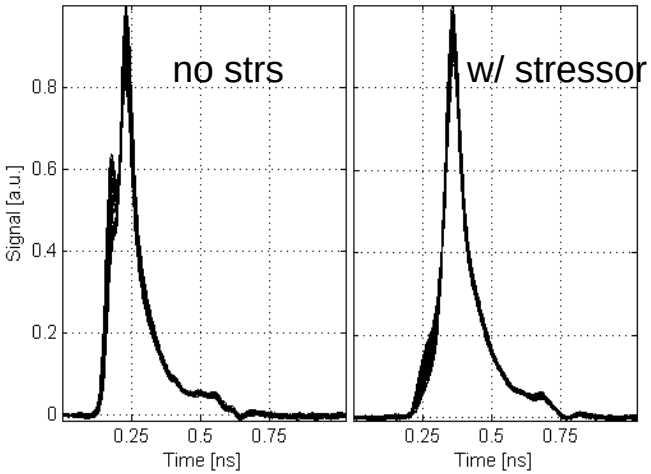




- Modern FDDI fibers
- Dots represent PIE-D computed from impulse response measurements with standard GbE offset patch cord
- Each point represents arbitrary input polarization state

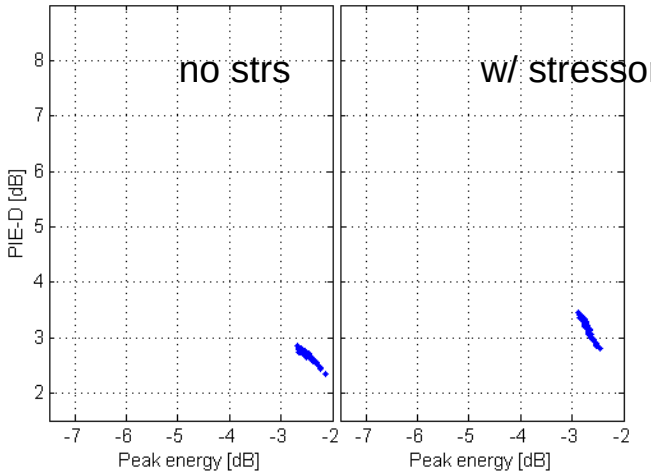


# Channel impulse response of 00115928A1 - fiber with well-behaved center and OSL DMD is little affected by offset.

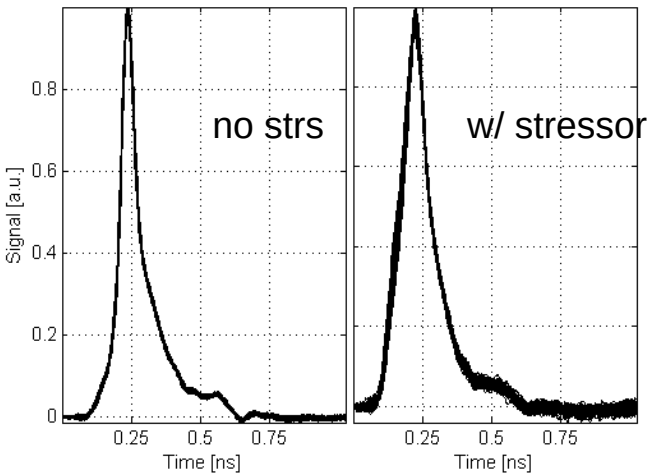
**Center launch**




**Center launch**

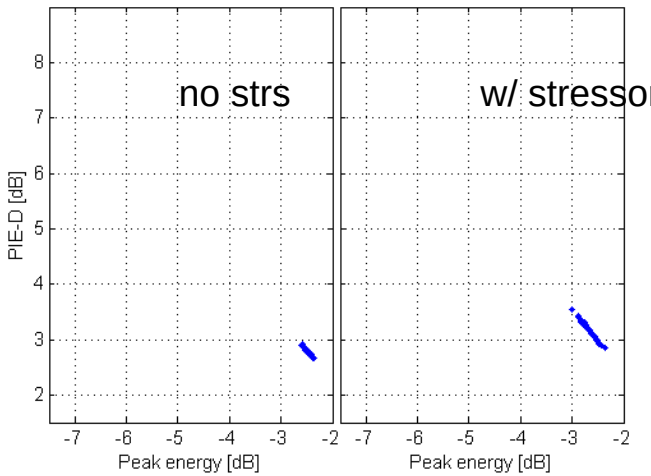



**Offset launch**




offset

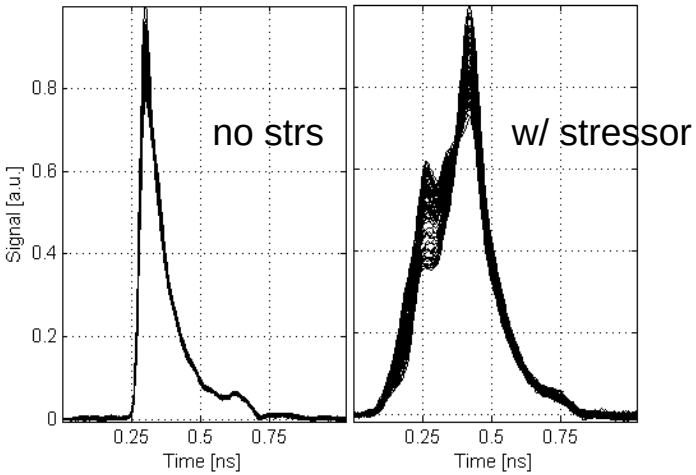
**Offset launch**



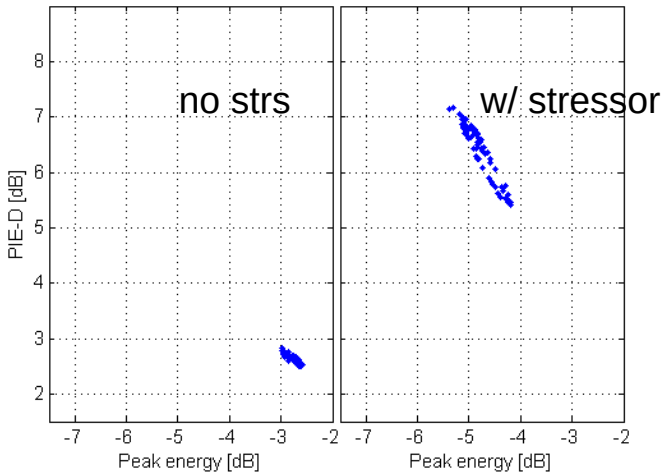
# Channel impulse response of 00092534AR – Fiber with good center but bad OSL DMD is severely affected by large offsets. 00109151AO and 00113951AF behave identically.



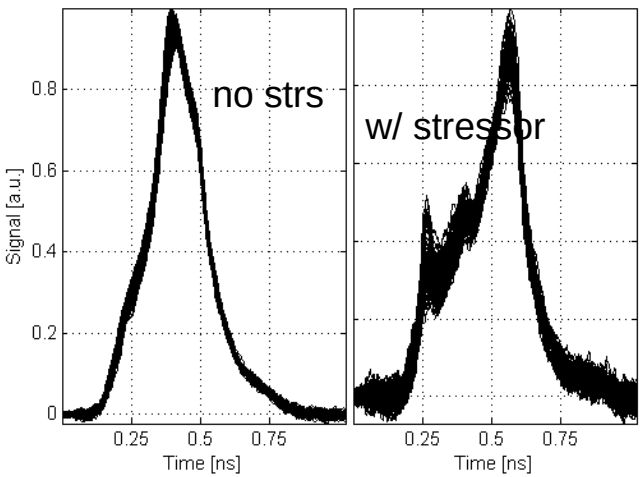
**Center launch**



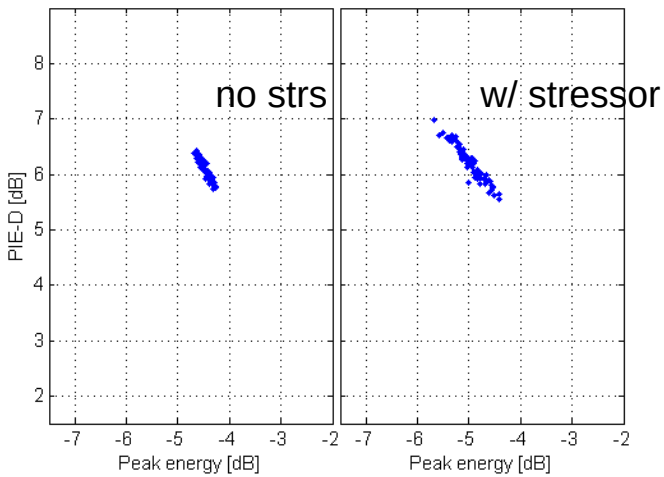

**Center launch**



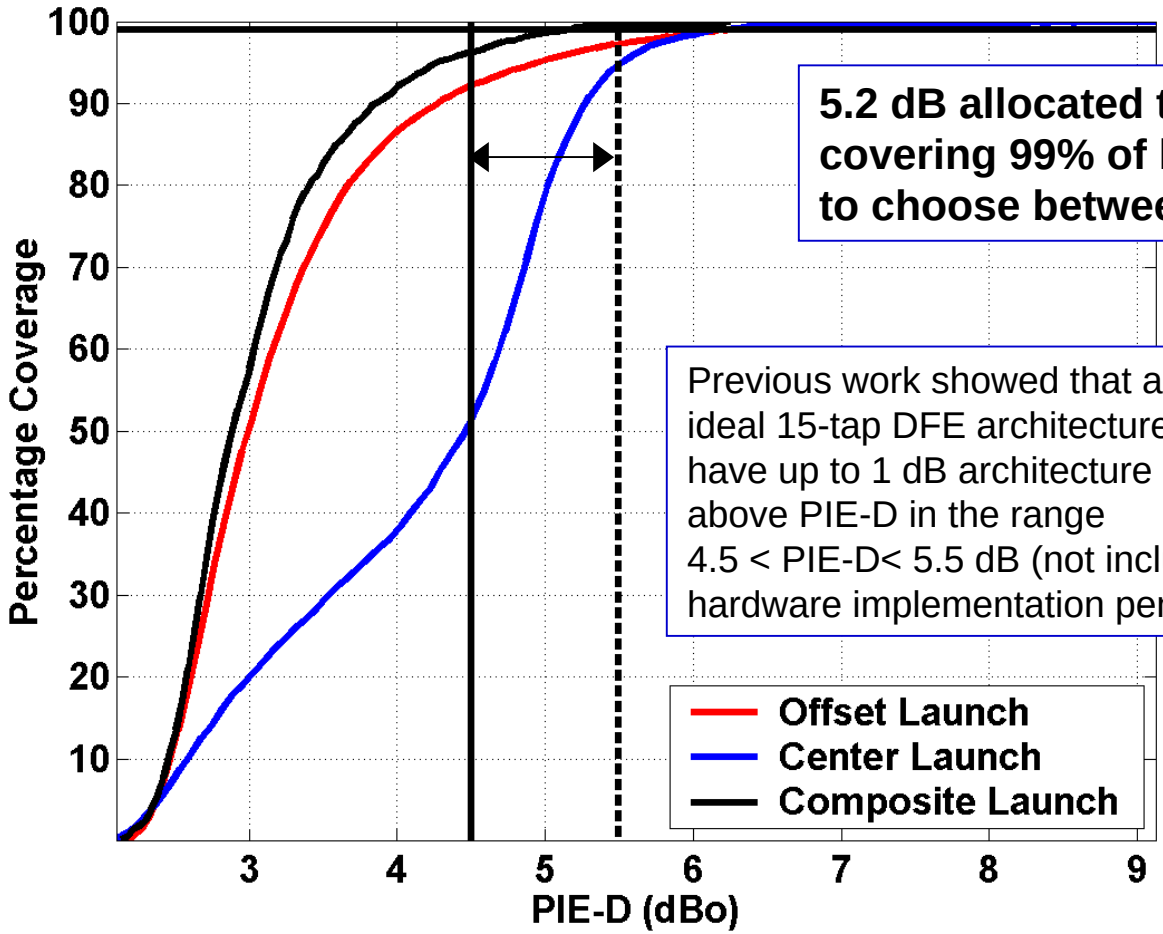

**Offset launch**




**Offset launch**



# Next Step – explore finite equalizer performance




**5.2 dB allocated to PIE-D is required for covering 99% of legacy fibers, with ability to choose between center and offset launch**

Previous work showed that an ideal 15-tap DFE architecture could have up to 1 dB architecture penalty above PIE-D in the range 4.5 < PIE-D< 5.5 dB (not including hardware implementation penalties)

# Conclusions

- 99th percentile PIE-Ds for 1998-era manufactured fiber have been analyzed
  - All fibers are > 500MHz-km OFL BW, FDDI fibers from sellable inventory
  - OSL bandwidths are consistent with assumptions of previous IEEE standards efforts, but represent a more complete characterization than available in the past.
  - This dataset is taken from the center of preforms (tuning region) and remains *optimistic* in that respect (like previous datasets used in standards efforts).
  - Range of Max-min centroid delays represented vary from < 0.1 ns/km to 2.8 ns/km
  - Offset launch ~ 6.3 dB
  - Center launch ~ 6.2 dB
  - Choose Optimal launch ~ 5.2 dB
  - Connector effects not directly included

- Polarization variations (equivalent to mechanical vibrations) are shown to result in a PIE-D spread of 1 to 2.5 dB for offset launch in FDDI fibers with broad impulse responses
- A single 10-micron offset (similar to two worst case 7-micron offset connectors) for modern, “kinked” FDDI fibers – with no or small center defect structure – were shown to raise PIE-D for center launch by 3 to 5 dB

# DMD for Four Modern FDDI fibers