MMF Channel Characteristics

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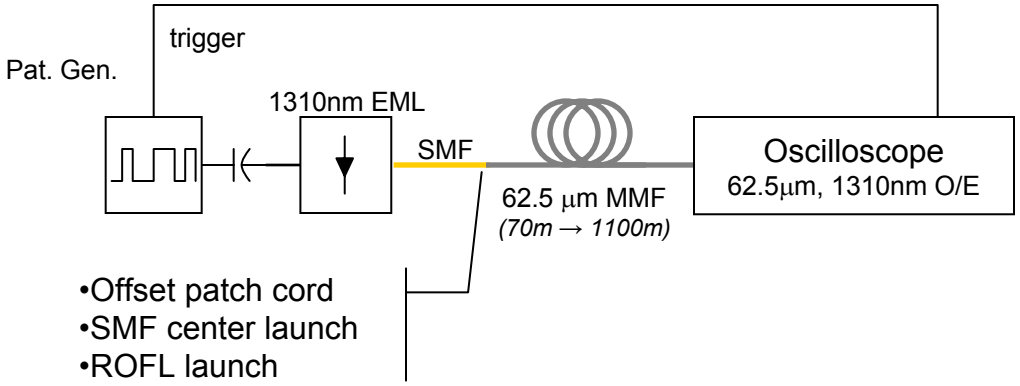
Motivation / Outline

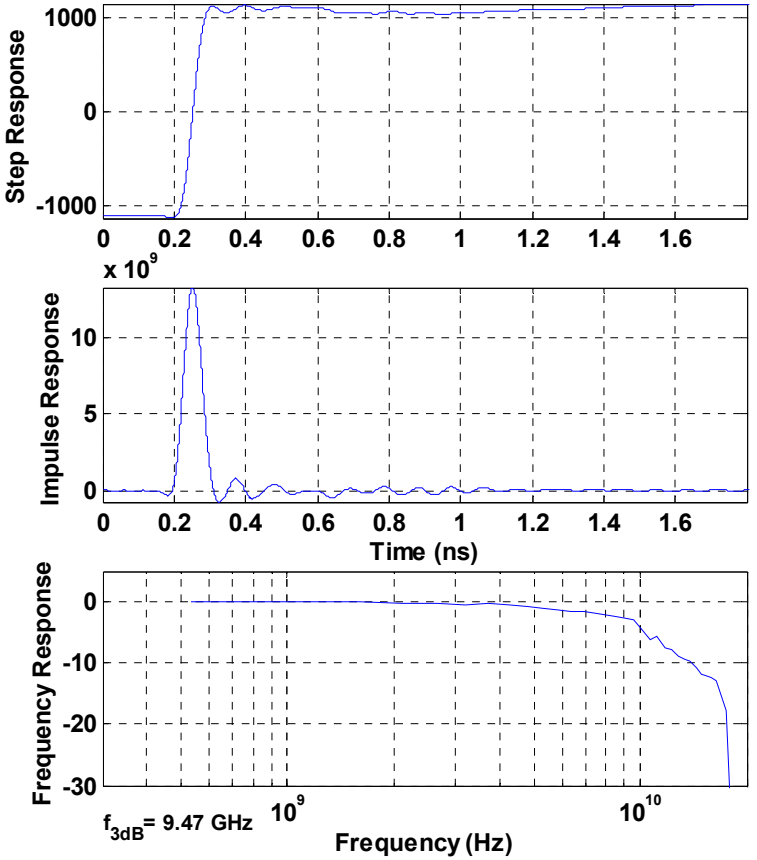
- Fiber impulse response
  - Critical importance of launch conditions, connectors, etc.
  - Variability of a single fiber
  - Initiate discussion of channel model, worst-case fiber, etc.

- Fiber measurements
  - Intended as illustration, not exhaustive study
  - “Typical” performance metrics: OFL bandwidth, DMD
  - Impulse response vs. launch

Test Setup: Fiber Impulse Response



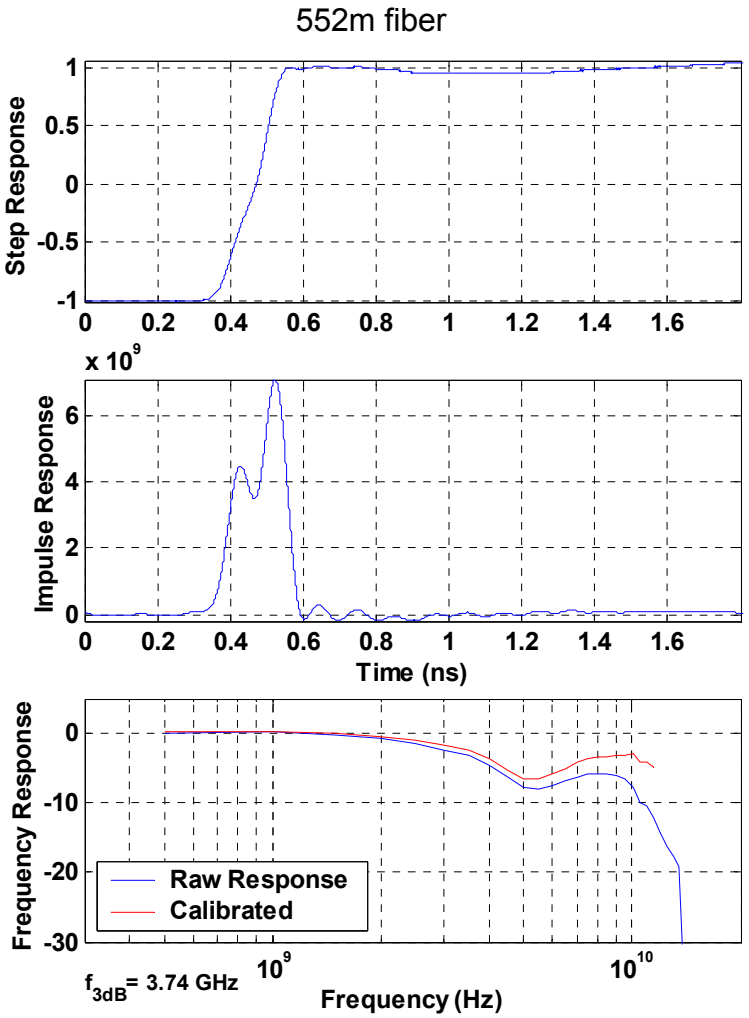
- EML source
  - Measure step response
  - Differentiate for impulse response
  - FFT for frequency response
- Measurement bandwidth ~9.5GHz



Calibration – 2m fiber

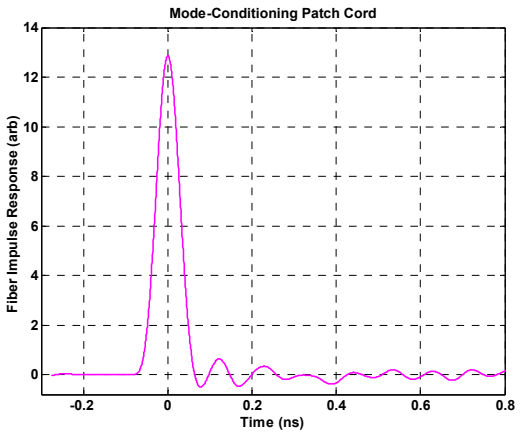
Fiber Characteristics

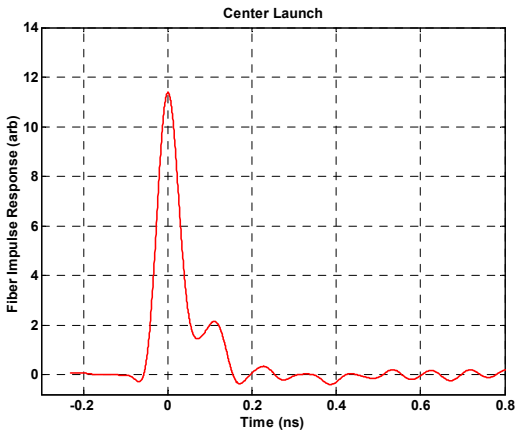
- 62.5μm MMF
- 2.2km spool cut back:
  - 1100m, 552m, 275m, 139m, 81m, 70m individual lengths
- "Off-the-shelf" fiber
  - No particular characteristics requested
- Overfilled Bandwidth Measurement
  - CPR ~ 33dB
  - BW corrected for measurement system bandwidth
  - Multiple fiber lengths measured & compared for consistency
  - BW ~ 2.0GHz-km

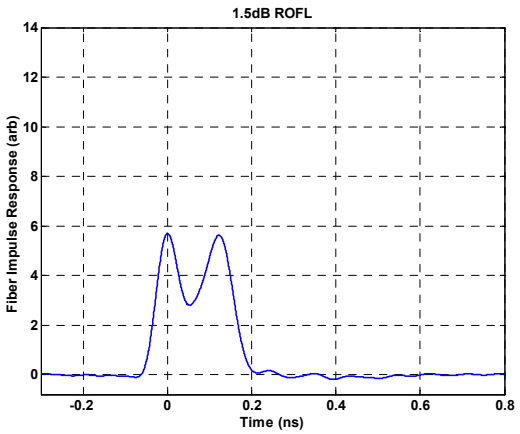


Fiber Response vs. Launch Condition (1/2)

Measured Fiber Response





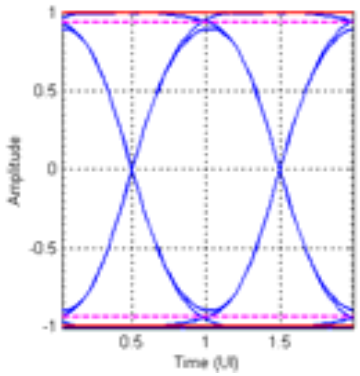


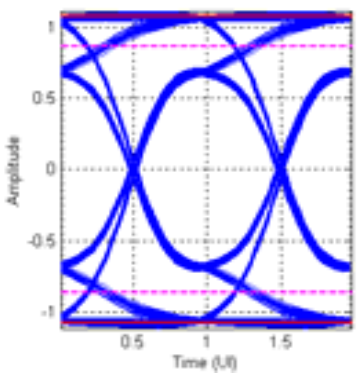
Offset Patch Cord

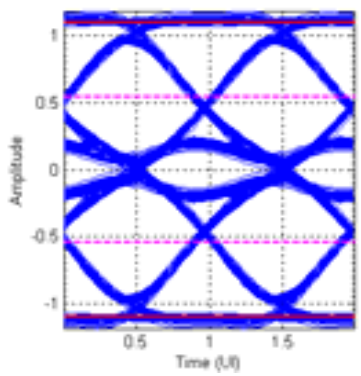
Center Launch

1.5dB ROFL

Simulated Eye Diagram

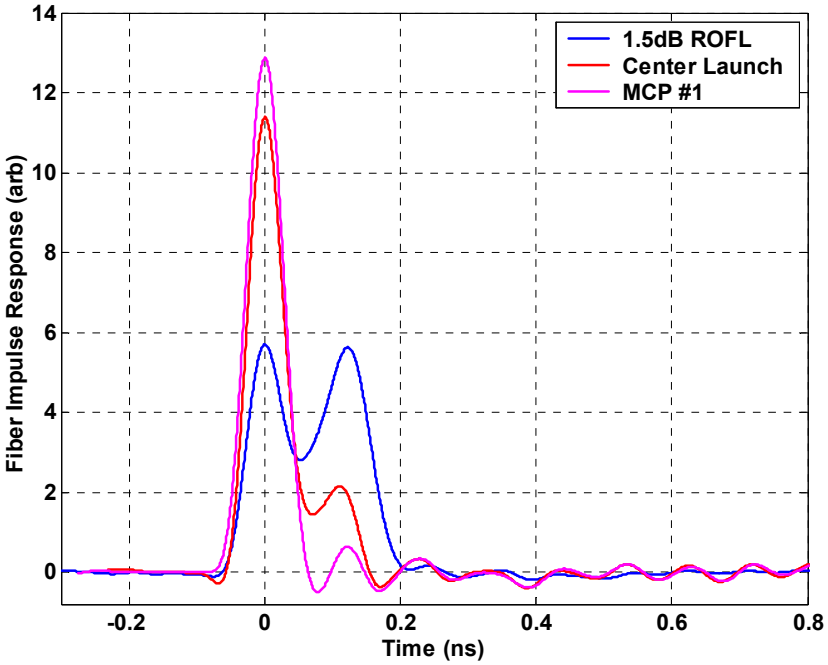






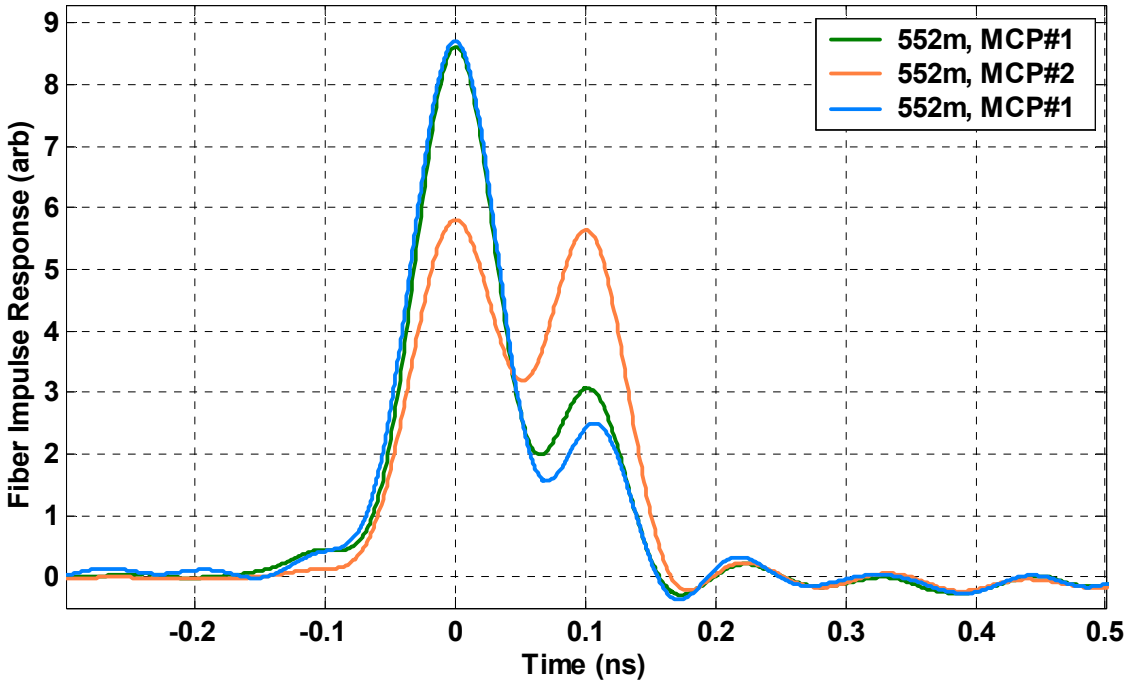
- 139m, 62.5μm MMF

Fiber Response vs. Launch Condition (2/2)



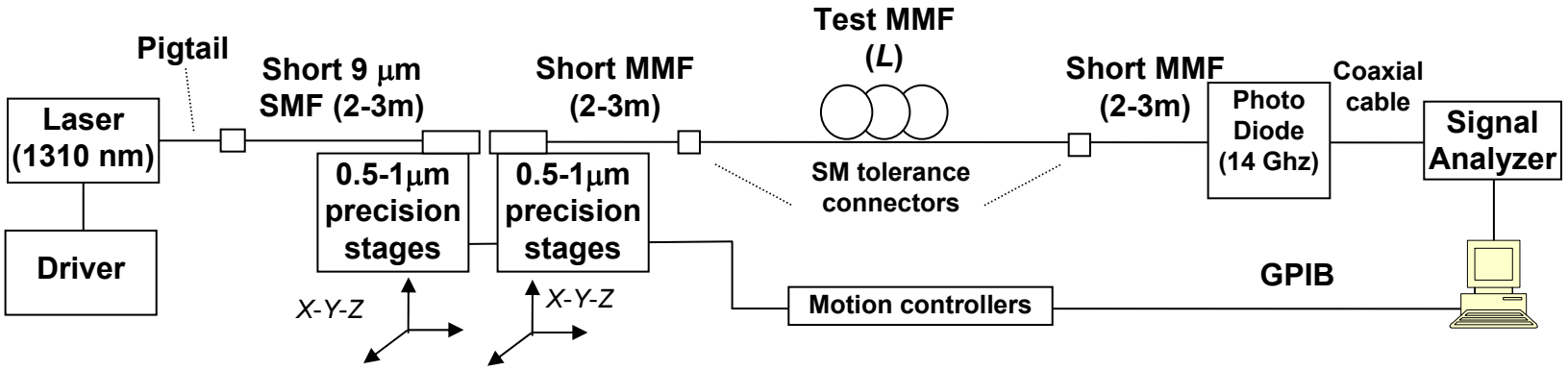
- 139m, 62.5μm fiber
- Three launch conditions
  - Mode Conditioning Patch Cord
  - Center launch
  - 1.5dB ROFL
- Multiple peaks in response
  - Significant differential delay among mode groups
  - $\Delta t \sim 125ps$
  - Poor eye diagrams

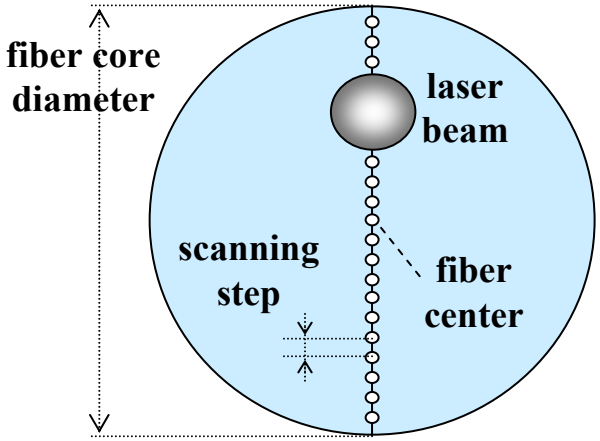
Mode Conditioning Patch Cord



- 552m, 62.5μm fiber
- Good measurement stability over time (blue, green)
- Dramatic difference with different patch cords

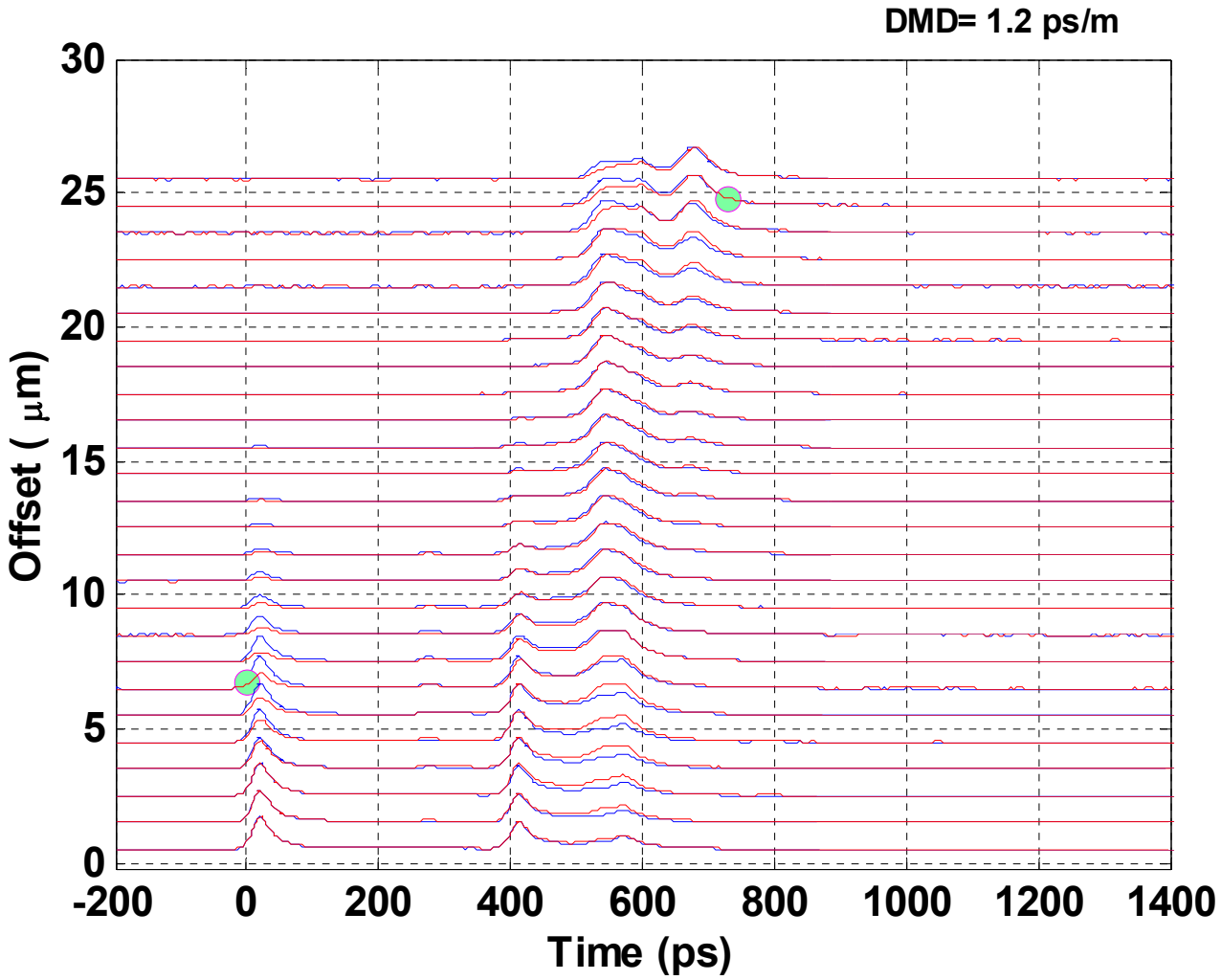
Test Setup: DMD Measurement





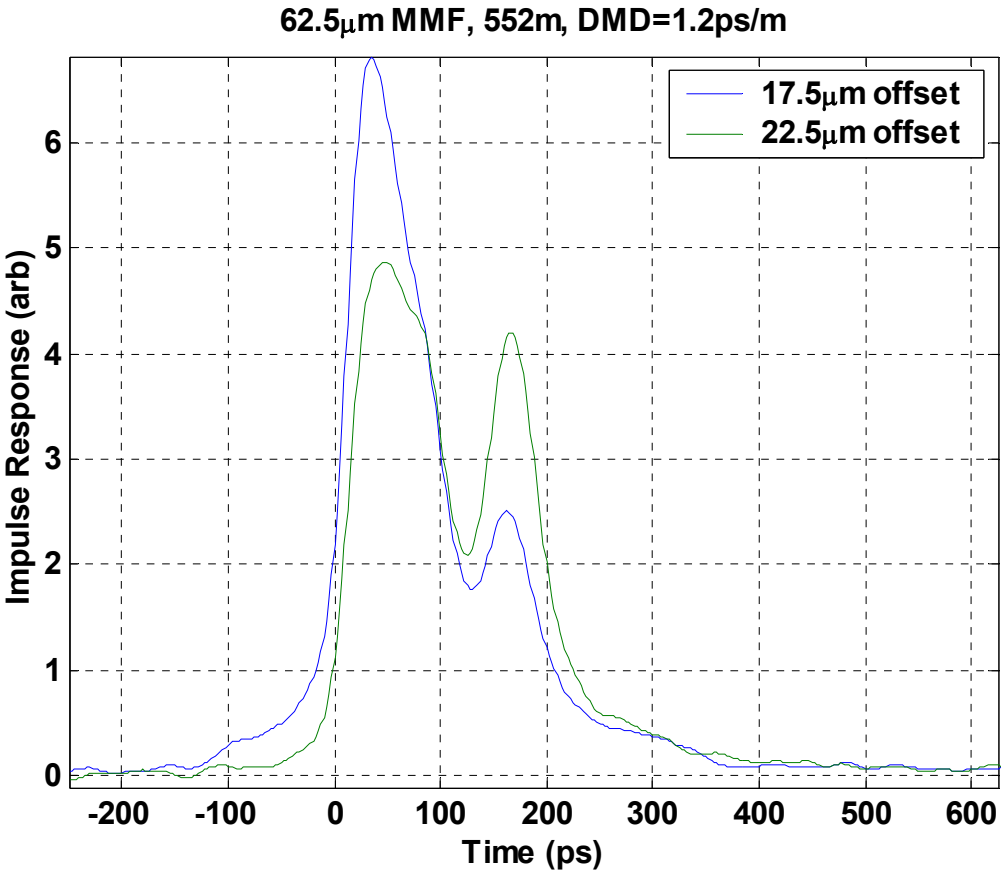
- 1310nm, gain-switched FP source
  - ~50ps pulse width (FWQM)
- -28 to +28 μm offset range
- 1 μm step scans

DMD Measurements (1/3)



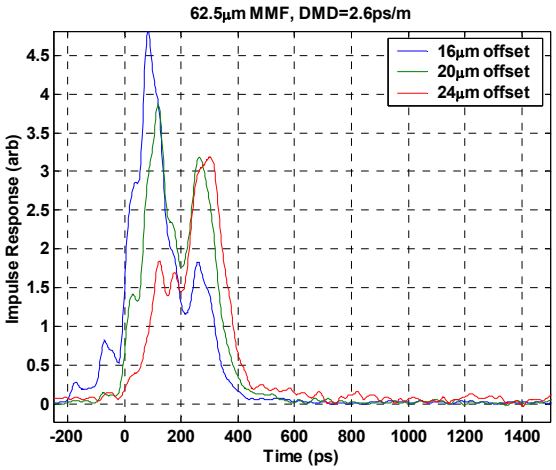
- 552m, 62.5μm MMF

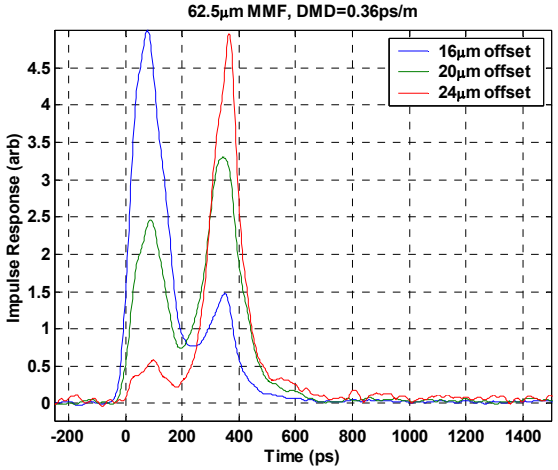
DMD Measurements (2/3)



- Results consistent with previous MCP measurements

DMD Measurements (3/3)

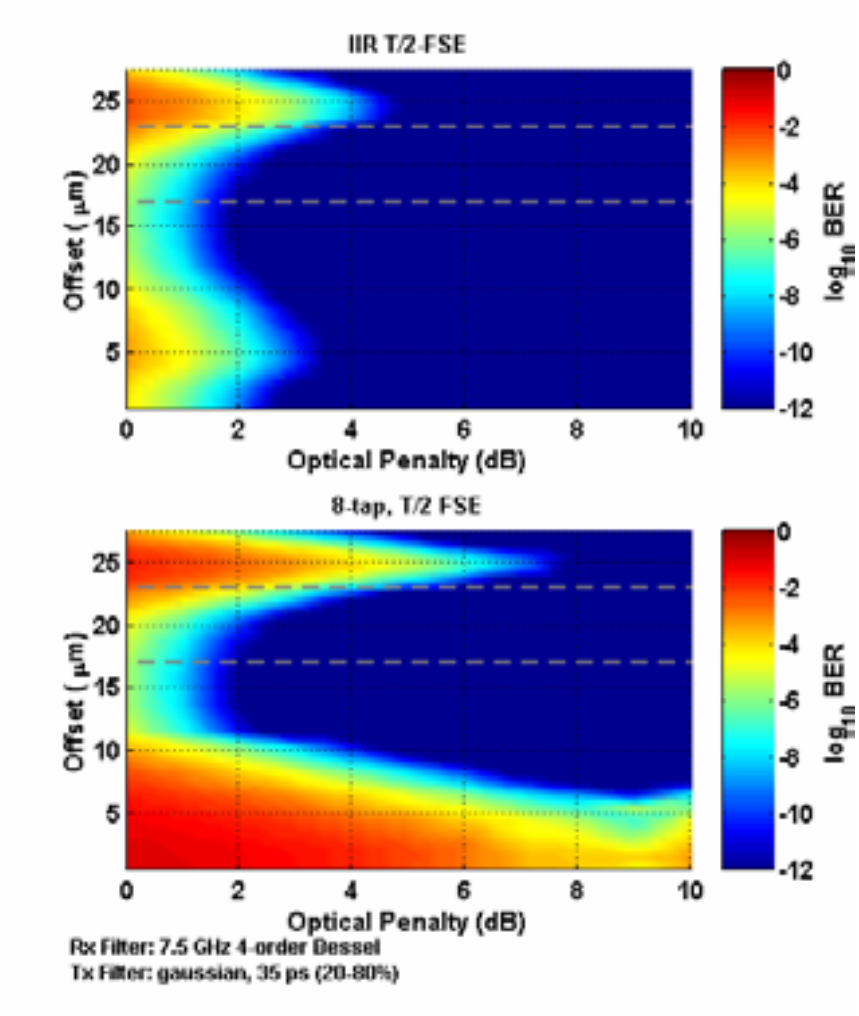




- Starting to look at other fibers
- Preliminary results suggest previous measurements are not atypical

EQ Simulation Example

- Ideal EQ (i.e. textbook simulation)
  - Infinite length, T/2-spaced linear equalizer
  - 8-tap, T/2 fractional-spaced linear equalizer
- Optical SNR penalty relative to 10^{-12} BER
- Measured impulse response
  - 552m, 62.5μm fiber
  - 7.5GHz, 4th-order BT receiver
  - 35ps rise/fall transmitter



Summary

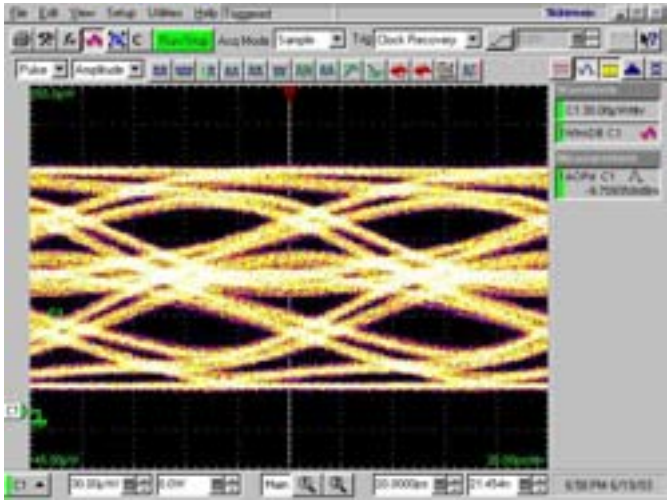
- Wide variation in impulse response from a single fiber
- Wide variation within tolerance specification of MCP
- Connectors – mode mixing can have significant effect on BW, without modal noise
- Significant precursor or postcursor ISI depending on launch condition
- Typical fiber performance metrics offer little insight
  - OFL bandwidth & DMD correlation to impulse response?

Observations

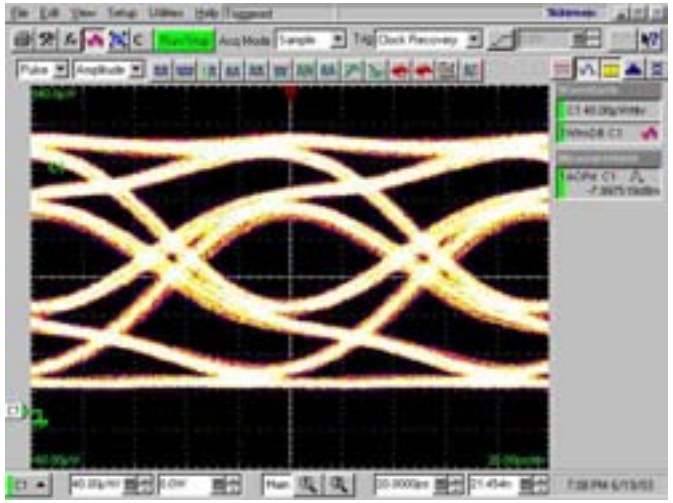
- Bandwidth is not a useful performance metric
  - Details of the impulse response determine actual performance
- DMD is not a useful performance metric
  - Scanning across the entire core of the fiber not representative of expected launch conditions
- “Controlling” the channel response seems impractical
  - Almost any mode power distribution (MPD) seems possible with reasonable tolerances on launch conditions
- Channel model requirements?
  - Assume “worst case” MPD – will depend on proposed solutions
  - Identify simple channel metrics, e.g. “restricted” DMD?
    - Time extent of impulse response for defined launch (with tolerance)

Backup

Connectors: Effect on Bandwidth



275m



552m

- 275m vs. 552m (same fiber pull)
  - Gives significantly worse output eye
  - Total insertion loss ~1.5dB
  - Connector quality poor