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Wavelength Dependence of Multimode Fiber Bandwidth & Dual Wavelength Channel Performance

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Outline

- Wavelength dependence of OM3/OM4 bandwidth
- Impact of two wavelengths on MPN
- Dual wavelength channel reach and BER performance
- Conclusions

Panduit's Ti:Sapphire DMD System

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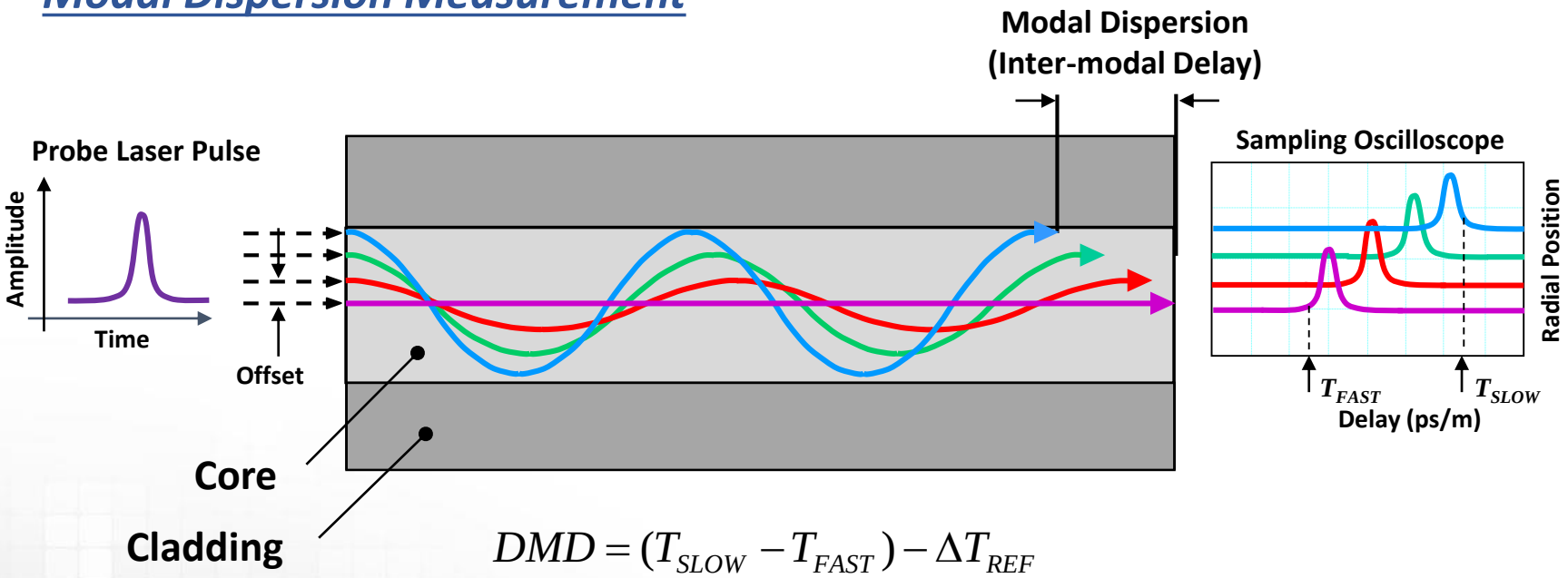
Underwriters Laboratories

0.1 micron spatial resolution

Differential Mode Delay (DMD) Measurement

DMD Test Bench - Tunable Titanium:Sapphire Laser

Modal Dispersion Measurement



$$DMD = (T_{SLOW} - T_{FAST}) - \Delta T_{REF}$$

$$\Delta T_{REF} = (\Delta T_{PULSE}^2 + \Delta T_{chrom}^2)^{1/2}$$

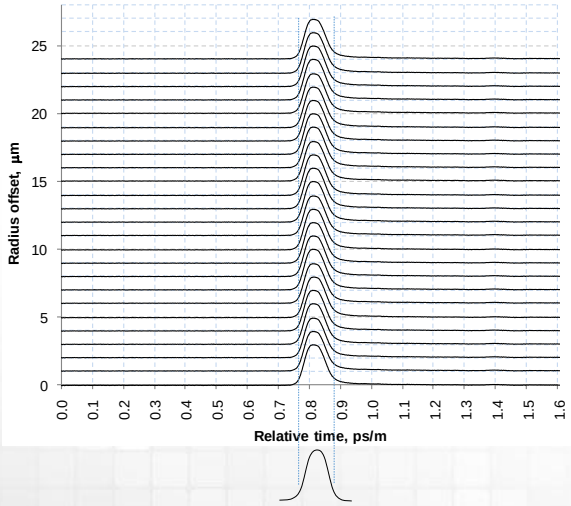
Used to calculate EMB

(Effective Modal Bandwidth)

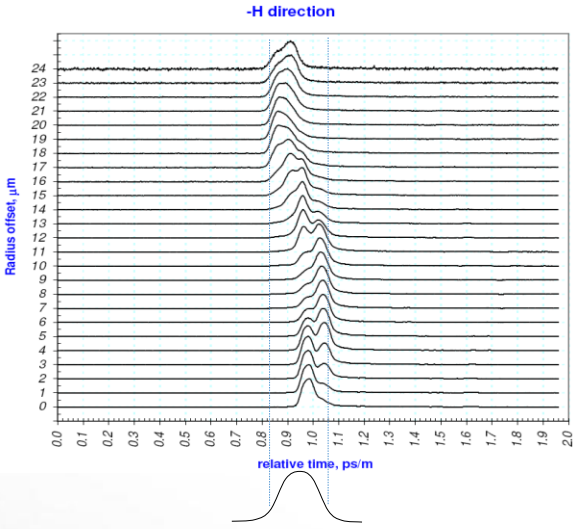
Two Examples of DMD

Due to process variation, each fiber has a unique DMD

As Designed

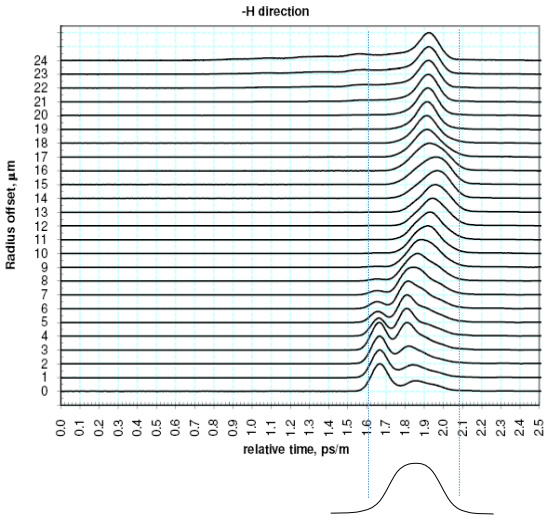


Fiber A



Left-Shifted

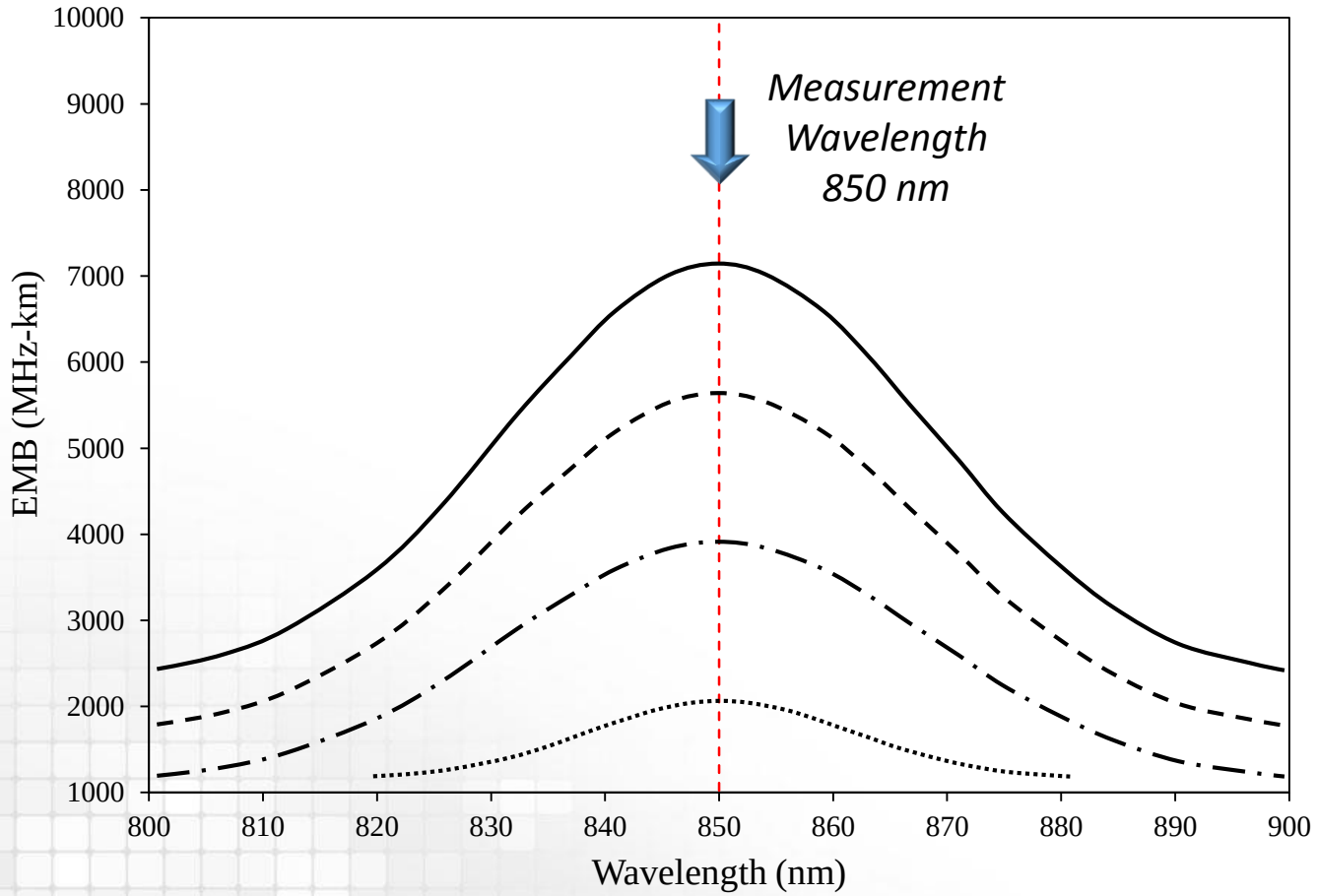
Fiber B



Right-Shifted

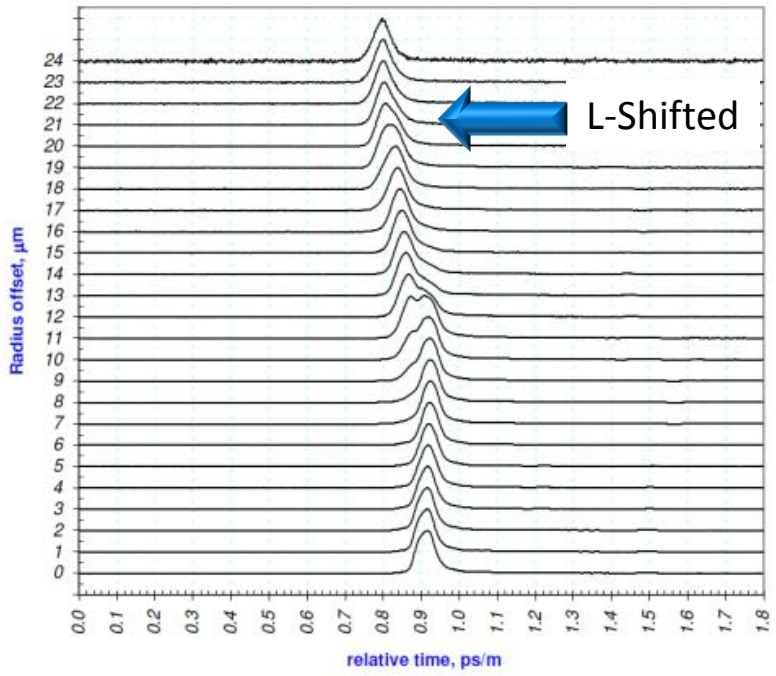
- ***Effectively No Fiber has an "As Designed" DMD Profile***

Widespread Belief – Wavelength Dependence of EMB Is Symmetric Around 850 nm



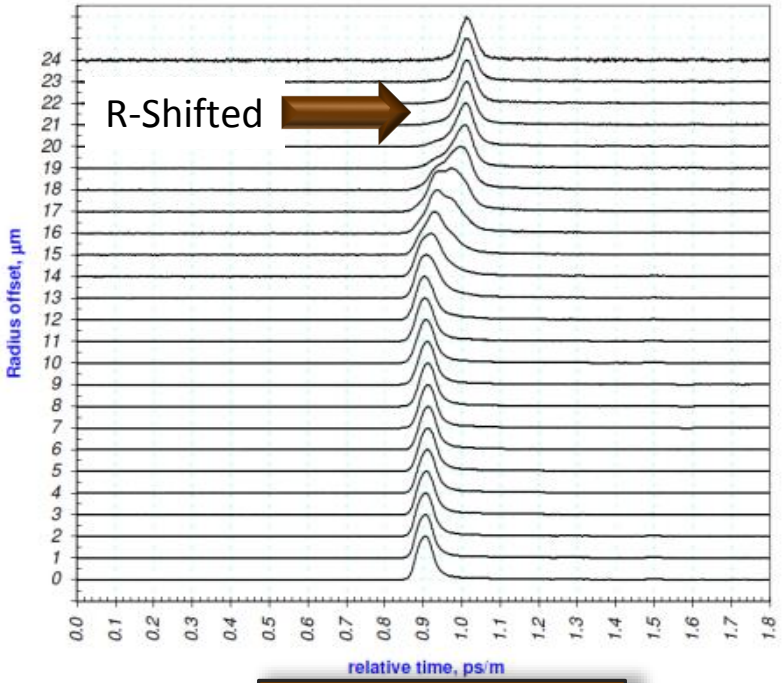
- *Two fibers from same cable with the same EMB (similar DMD profile)*
  - *L = 548 m*
  - *Ti:Sapphire Laser - DMD*

Fiber A



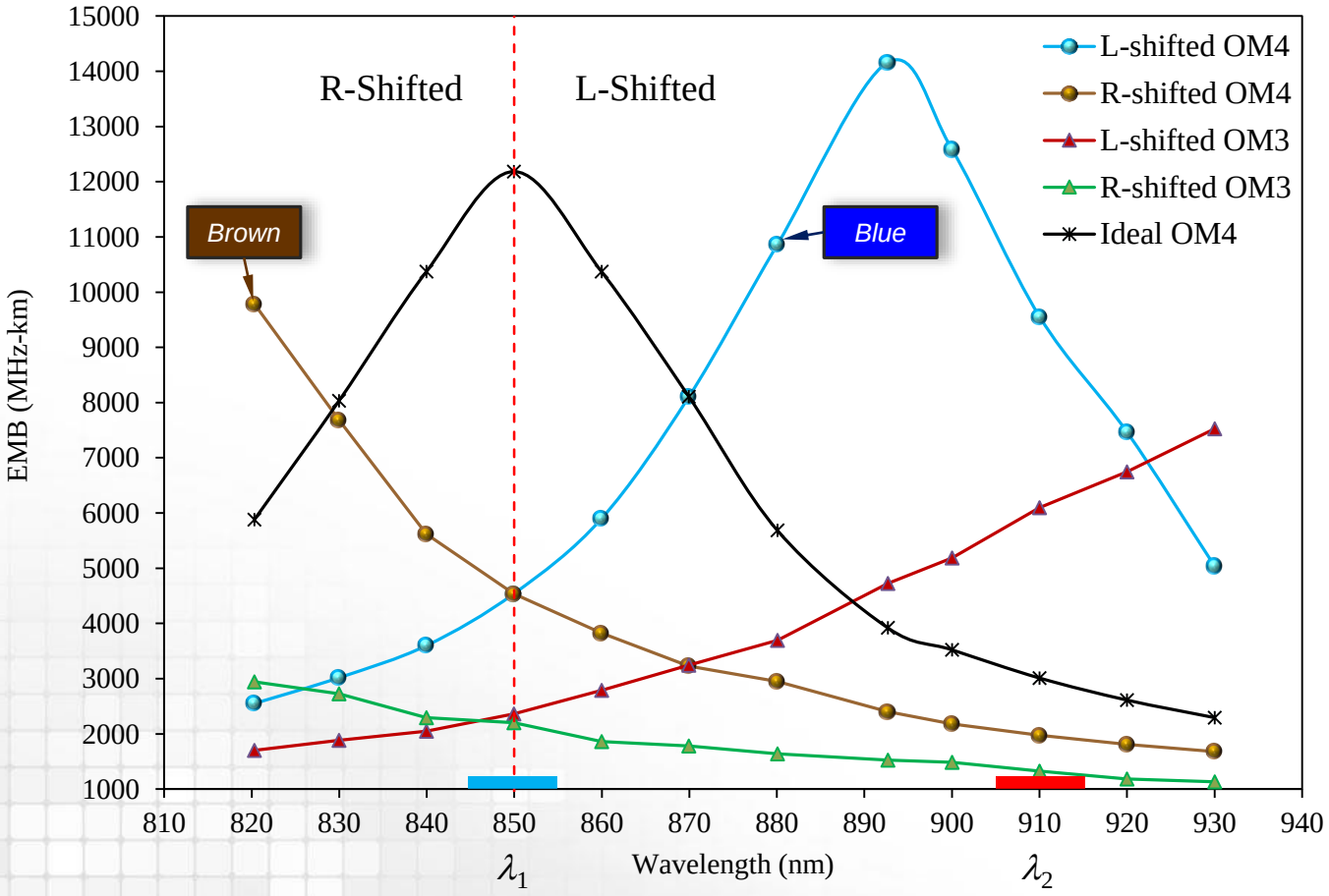
Blue Fiber
EMB = 4540 MHz·km
DMD_{inner} = 0.12 ps/m
DMD_{outer} = 0.15 ps/m
$DMD_{sliding}$ = 0.11 ps/m
DMD P-Shift = -0.098 ps/m

Fiber B



Brown Fiber
EMB = 4540 MHz·km
DMD_{inner} = 0.12 ps/m
DMD_{outer} = 0.13 ps/m
$DMD_{sliding}$ = 0.13 ps/m
DMD P-Shift = +0.096 ps/m

Measured EMB Wavelength Dependence
Panduit's DMD System Utilizes a Tunable Ti:Sa Laser



Fiber A (Left-shifted) Wavelength Dependence [1]

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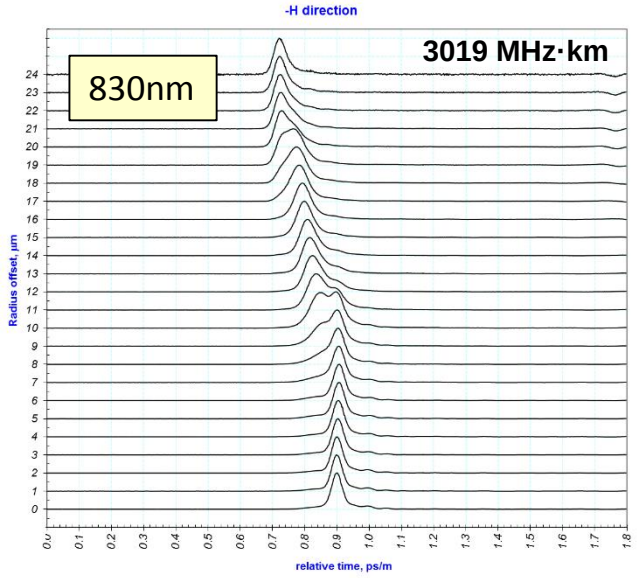

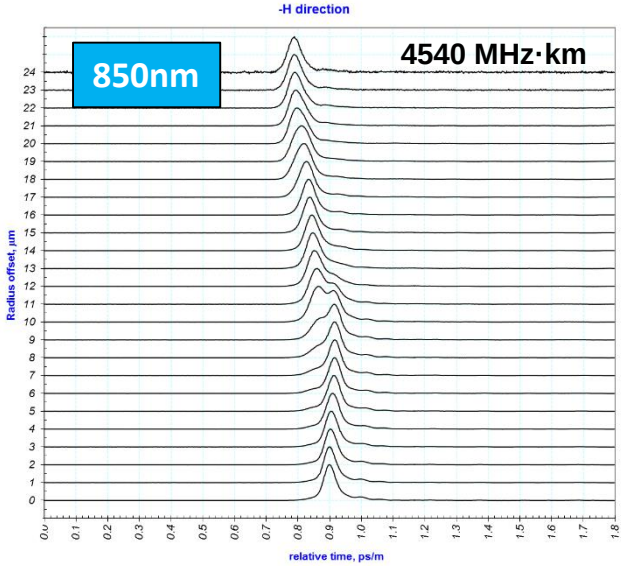

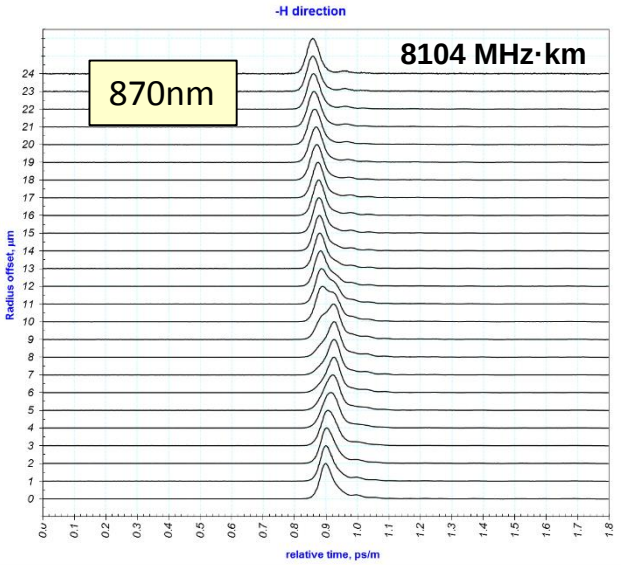

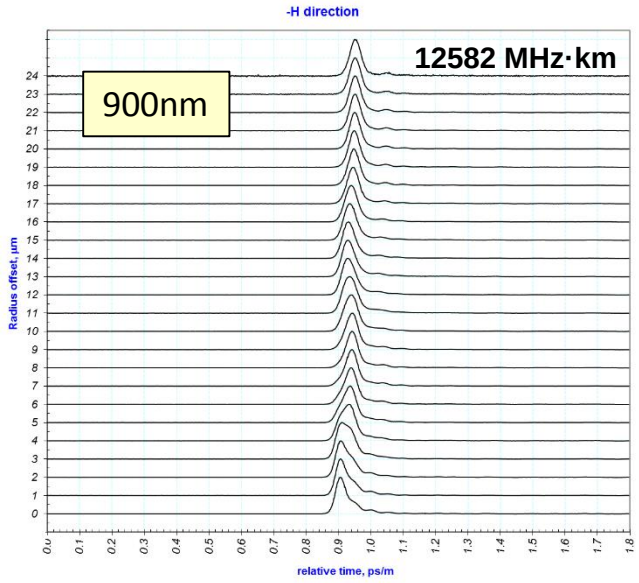

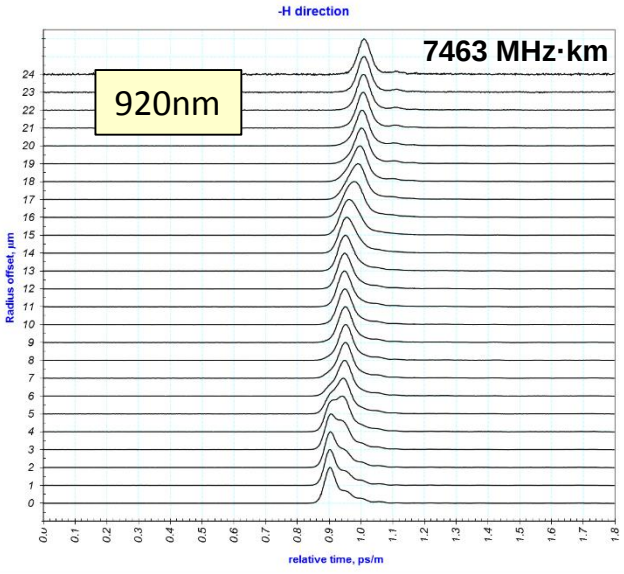

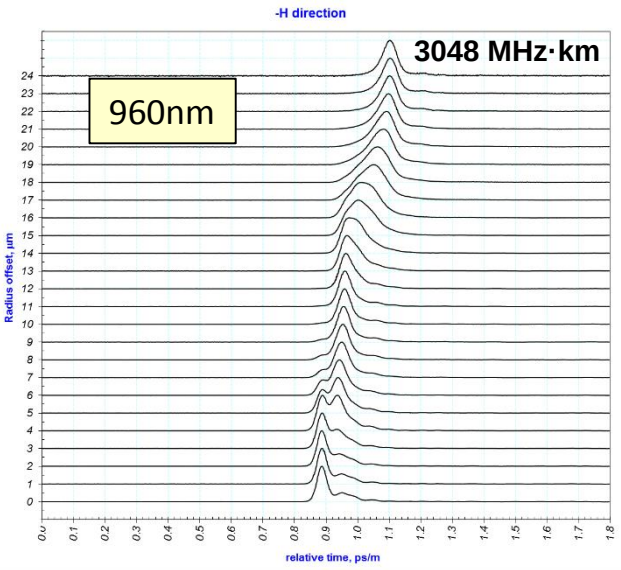

Fiber B (Right-shifted) Wavelength Dependence [1]

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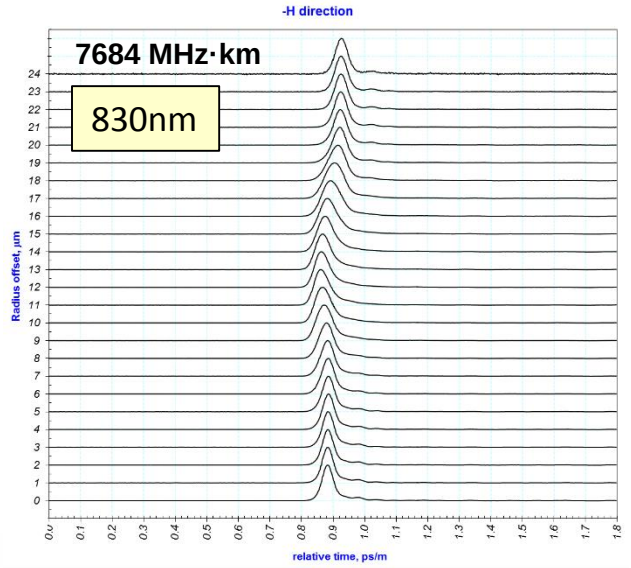
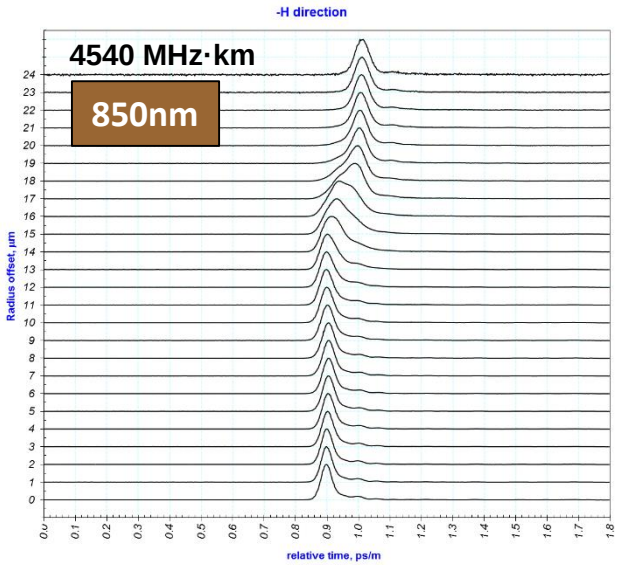
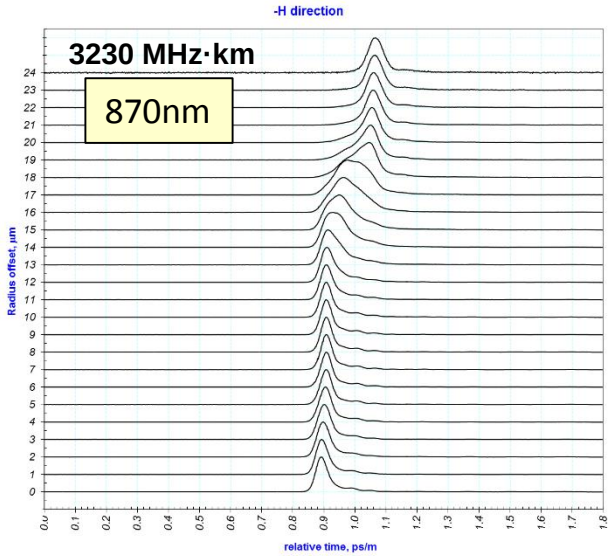
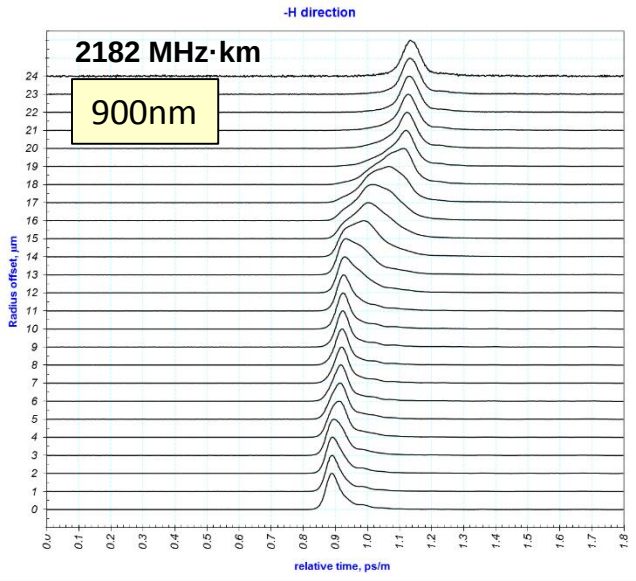
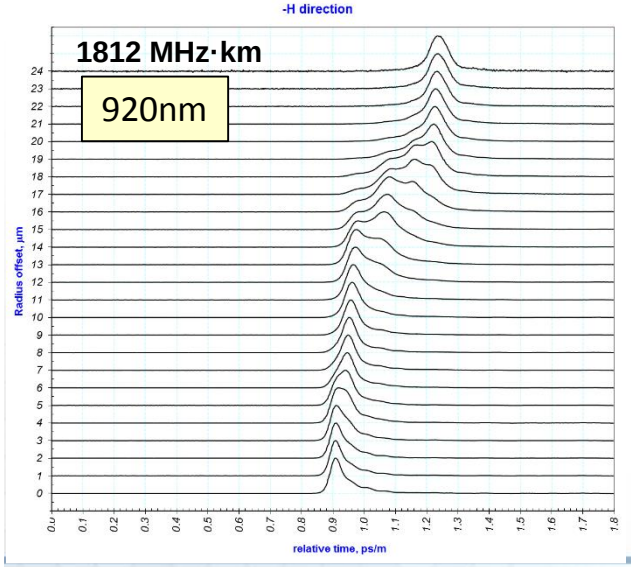
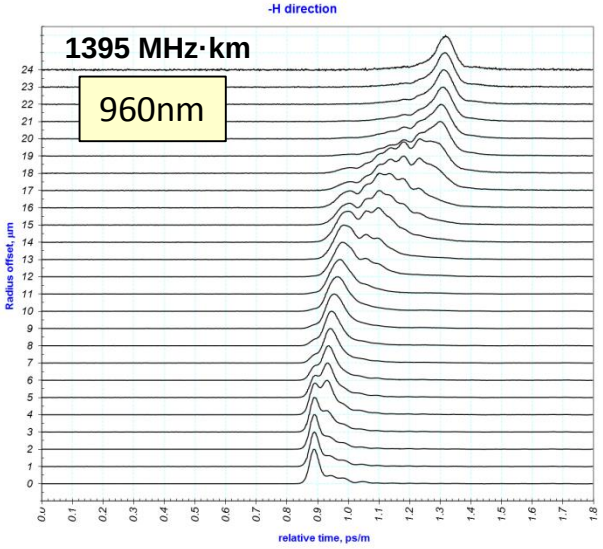








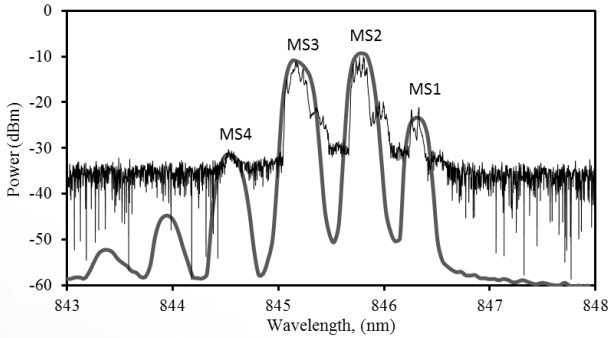




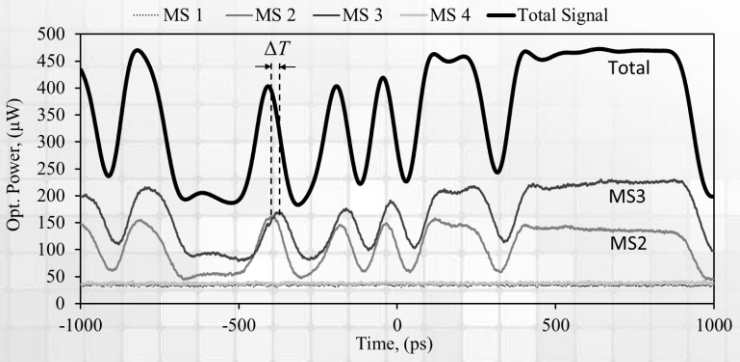
Impact of DMD profile on channel performance [2,3]

Bandwidth and Noise dependence on DMD tilt

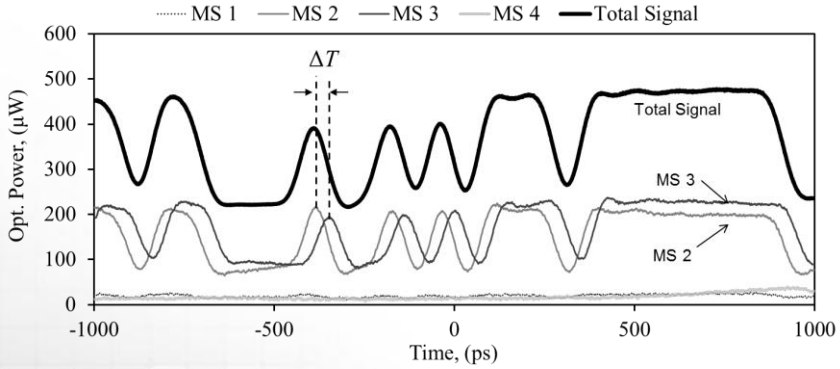
- For a similar EMB measured at 850nm, L-MMFs provide higher bandwidth at longer wavelengths than R-MMF.
- R-MMF produces higher levels of MPN due to longer separation of the modes in the MMF.
- Transceivers using equalization can partially compensate for channel bandwidth limitations. However, equalizers increase noise.



L-MMF



R-MMF



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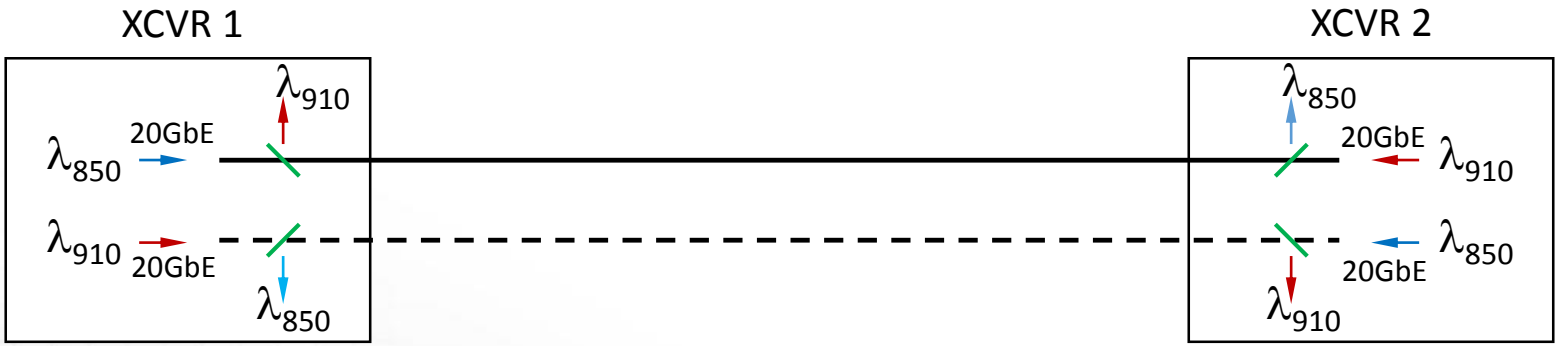
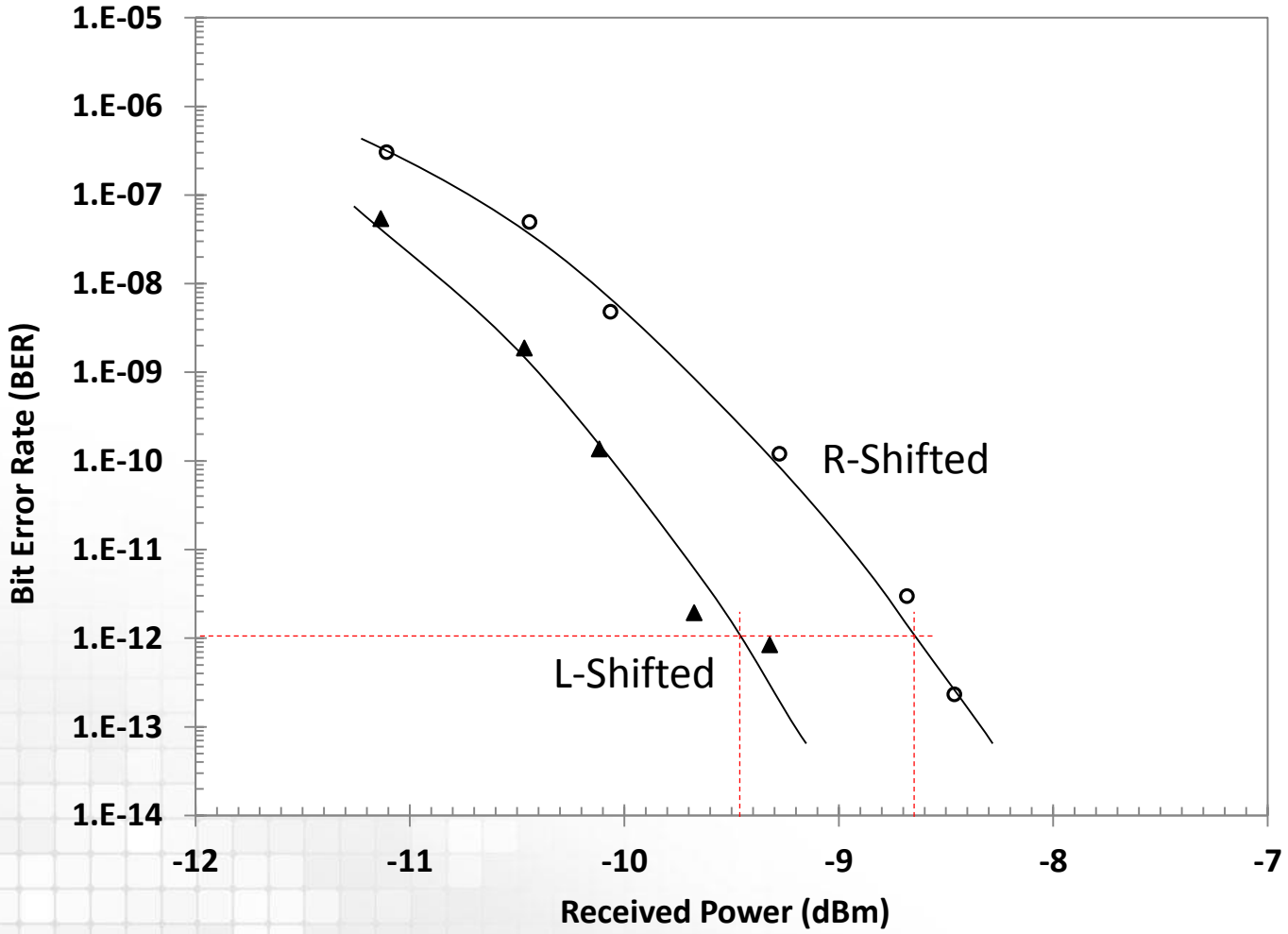
40GbE (2x20G) Bi-Directional, 2-λ's Measured Channel Performance

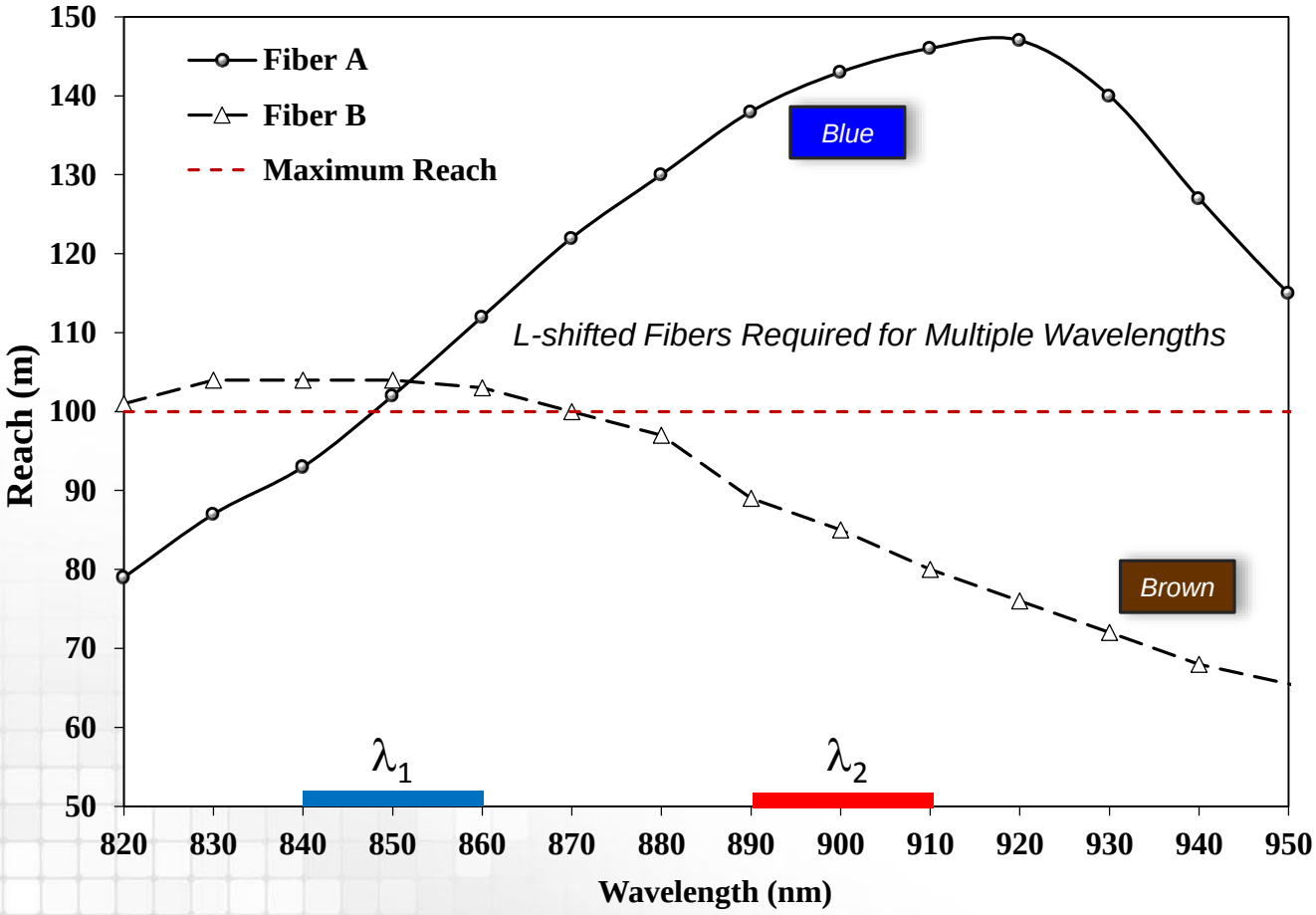


BER at 904 nm, 40Gbps, 150m
L- vs. R-Shifted DMD, EMB = 4540 MHz·km [4]



Calculated Channel Reach For 40G BiDi XCVR

Using Measured EMB Wavelength Dependence



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Conclusions

- Process variation in the fabrication of MMF refractive index profiles result in MMFs with optimized bandwidth at different wavelengths.
- Current OM3/OM4 standard test methods do not estimate EMB for wavelengths longer than 850nm.
- OM3/OM4 reaches for wavelength longer than 860 nm need to consider worst-case standard compliant fiber.
  - OM3/OM4 fibers can be L-MMF or R-MMF which has significant impact on performance. [4]
  - R-MMF has reduced bandwidth and produce higher levels of noise in equalized channels
- Channel Reach for a multi-wavelength PMD requires further study and must be based on worst-case variation in refractive index profile.

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References

1. R. Pimpinella, B. Kose, and J. Castro, “Wavelength Dependence of Effective Modal Bandwidth in OM3 and OM4 Fiber and Optimizing Multimode Fiber for Multi-Wavelength Transmission,” Proceedings of the 63rd IWCS, 2014.
2. J. Castro, R . Pimpinella, B. Kose, and B. Lane ,“Mode Partition Noise and Modal-Chromatic Dispersion Interaction Effects on Random Jitter,” J. Lightw. Technol., vol.31, no. 15, August 2013
3. J. Castro, R . Pimpinella, B. Kose, and B. Lane ,“Advances in characterization of the VCSEL mode partition noise penalty in optical fiber channels,” OFC 2014, Th2A.13.pdf
4. J. Castro, R. Pimpinella, B. Kose, B. Lane, “Investigation of the Interaction of Modal and Chromatic Dispersion in VCSEL-MMF Channels,” J. Lightw. Technol., vol. 30, no. 15, August 2012