Wavelength Dependence of Effective Modal Bandwidth (EMB)

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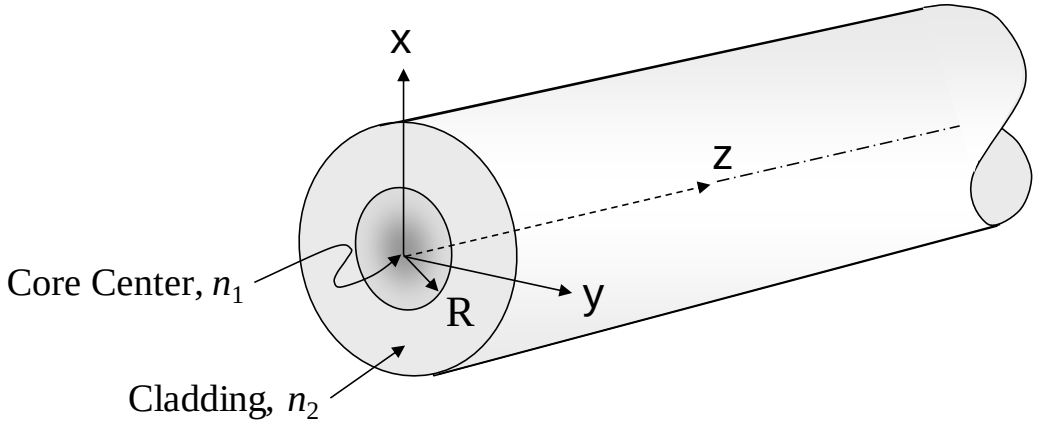
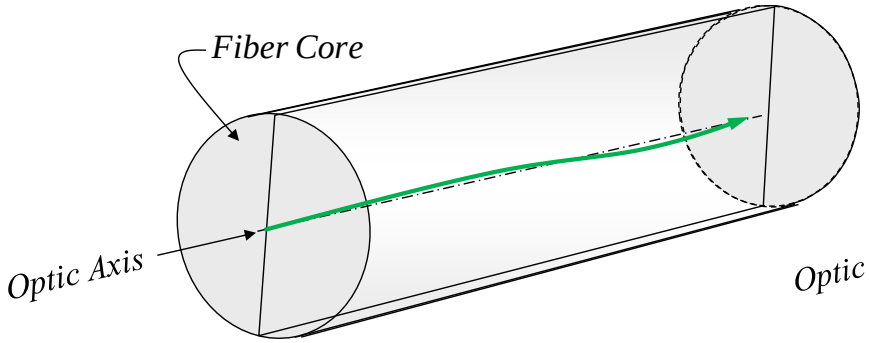
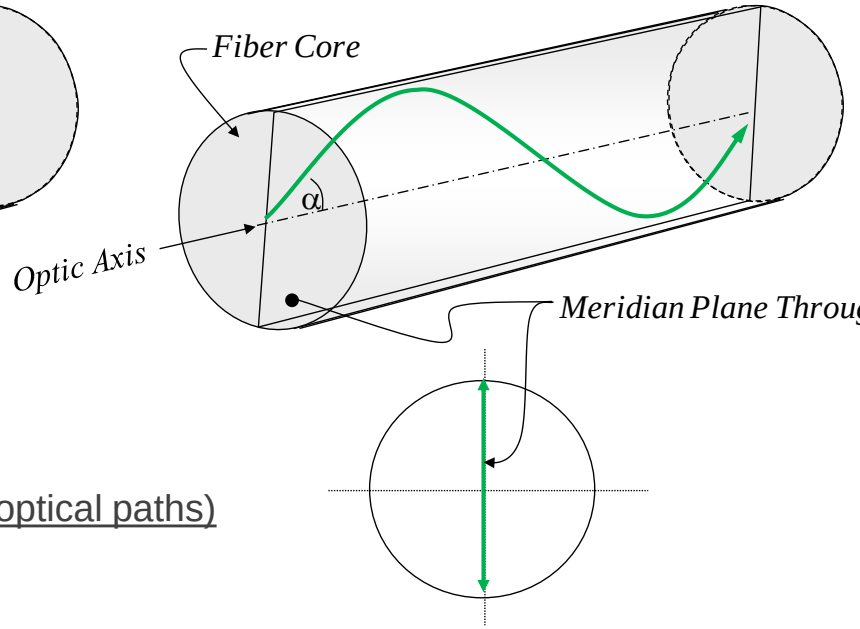
Multi-Gigabit Automotive Optical PHY Study Group
Ad hoc Telecon, October 13, 2020

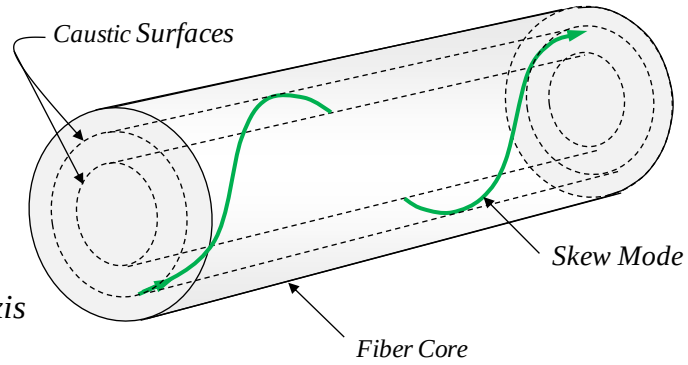
Fiber Modes in Multimode Fiber

A pulse of light splits and travels along different optical paths









Three possible modes (optical paths)

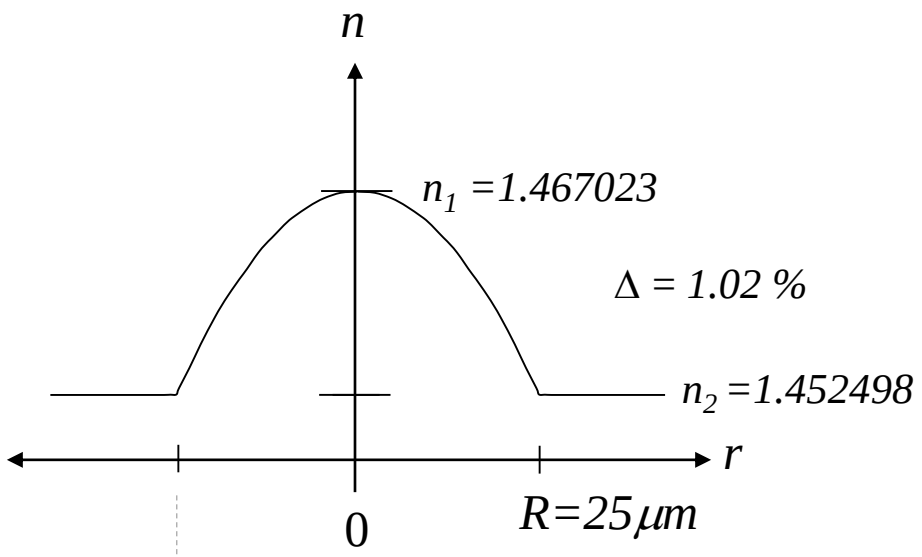
OM3, OM4, & OM5 Core Refractive Index Profile

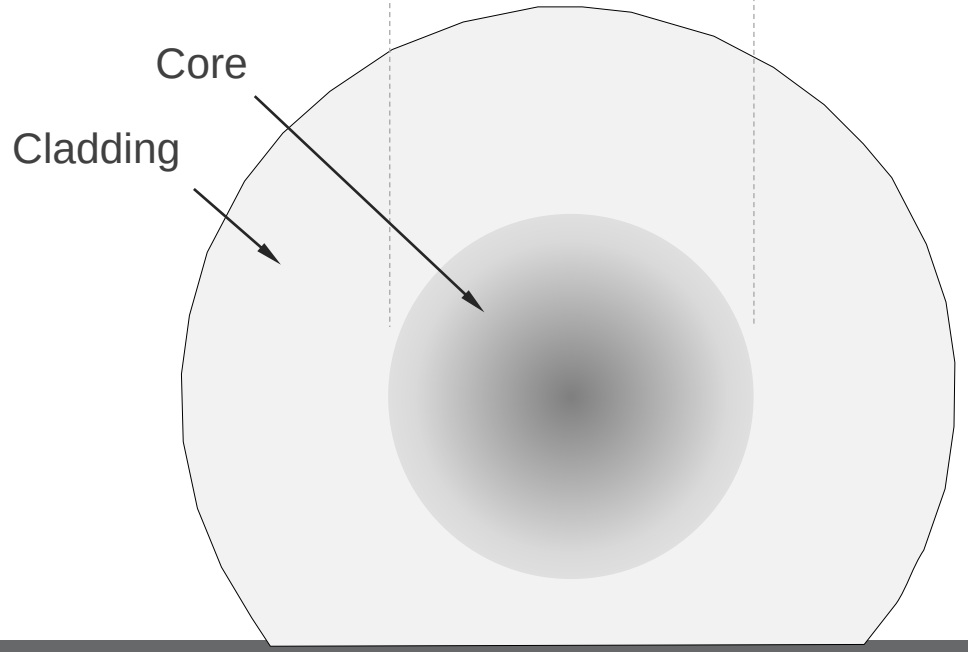
$$n(r) = n_1\left[1 - 2\left(\frac{r}{R}\right)^{\alpha}\Delta\right]^{1/2}$$

where,

$\alpha \sim 2$ *for 850 nm*

$$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2}$$



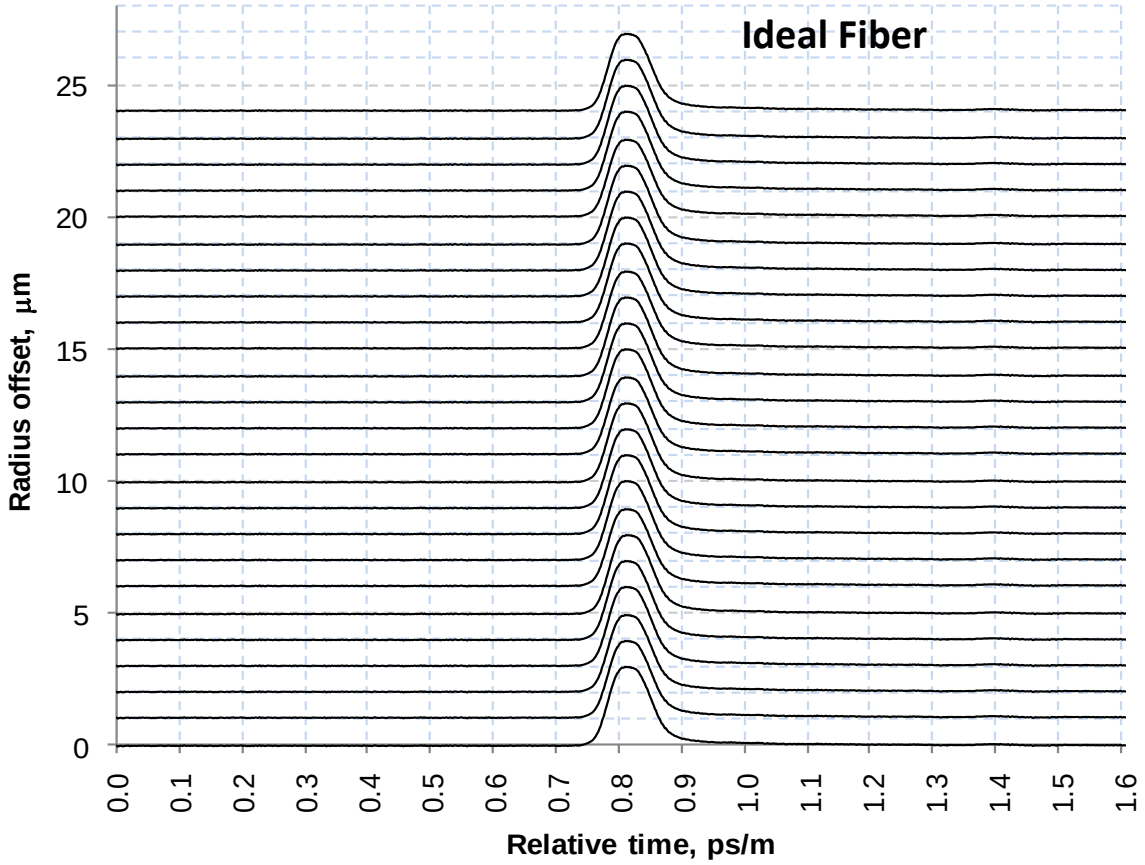


$$n = \frac{c}{v}$$

or, $$v = \frac{c}{n}$$

Differential Mode Delay (DMD)

Laser Optimized Multimode Fibers (OM3, OM4, and OM5 (Wideband), are designed so that all radial mode groups have the same delays –



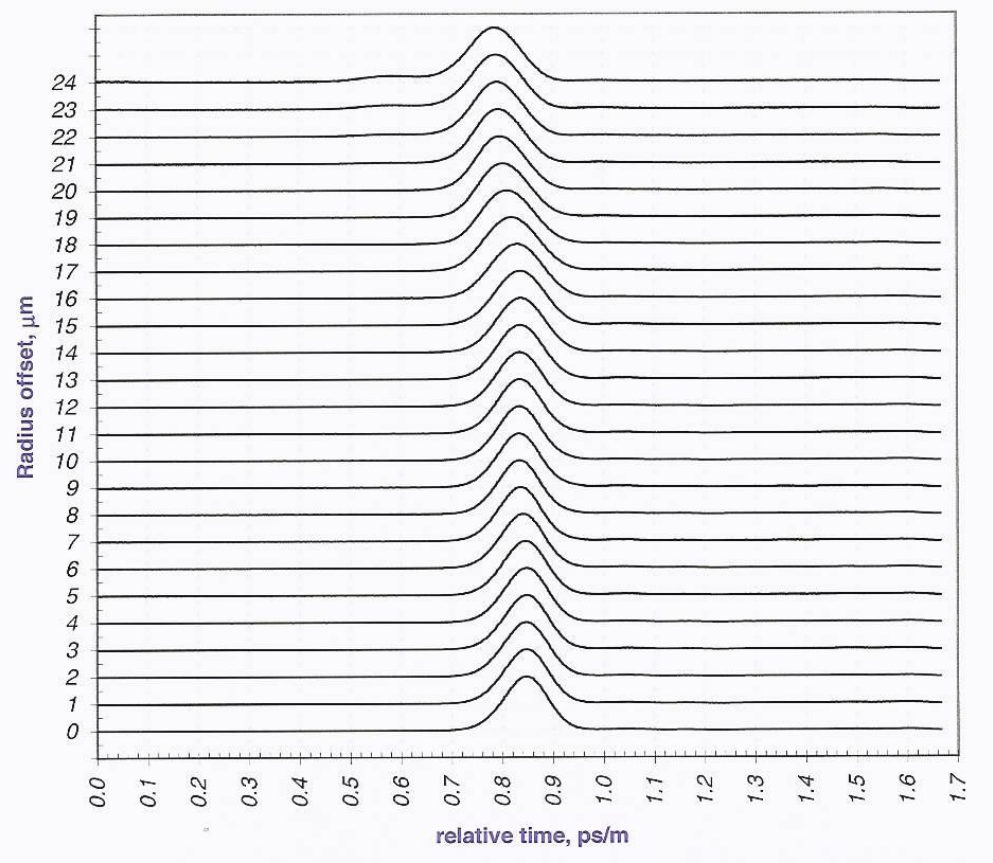
Effective **M**odal **B**andwidth (*EMB*)

Is calculated from

the DMD waveforms

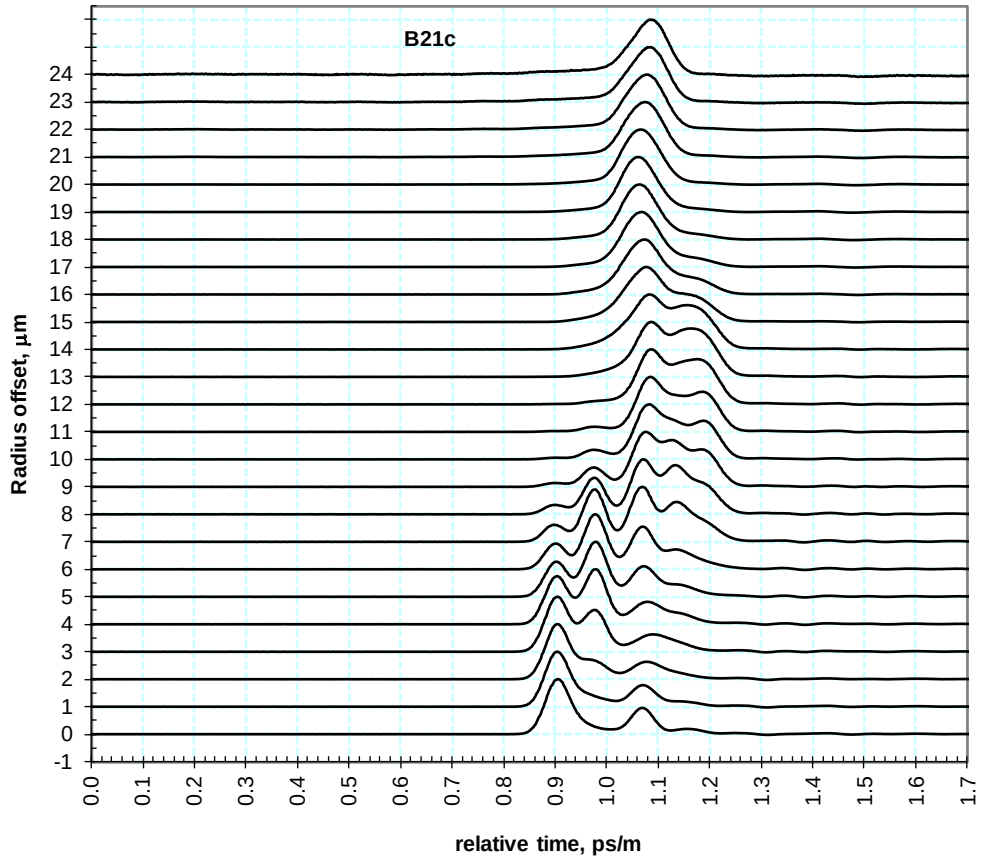
Two Examples of DMD Plots

Low Modal Dispersion, High Bandwidth



EMB = 6343 MHz·km
OM4

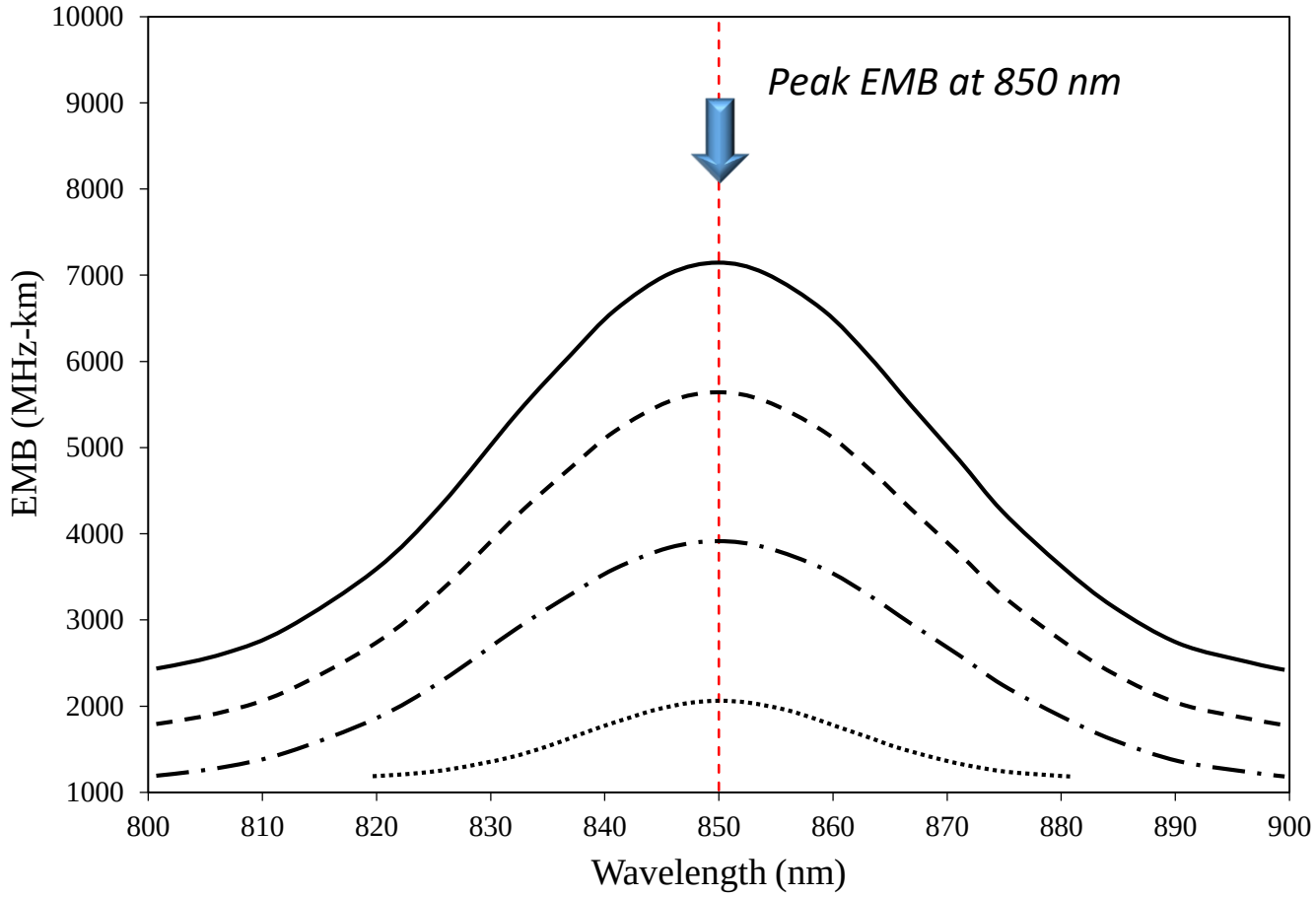
High Modal Dispersion, Low Bandwidth

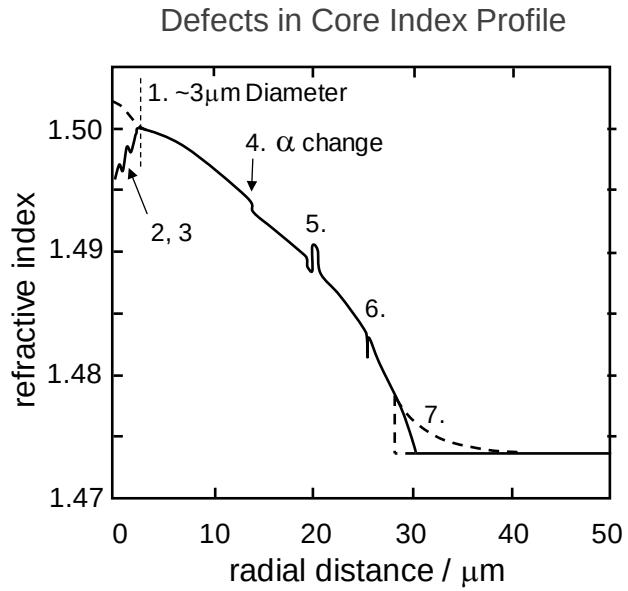


EMB = 2011 MHz·km
(OM3)

Previous understanding of Multimode Fiber Bandwidth

- *Peak EMB is at 850 nm and falls off symmetrically around 850 nm*
- *Reduction in EMB is due to refractive index profile defects*





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Tunable Titanium:Sapphire Mode Locked Laser

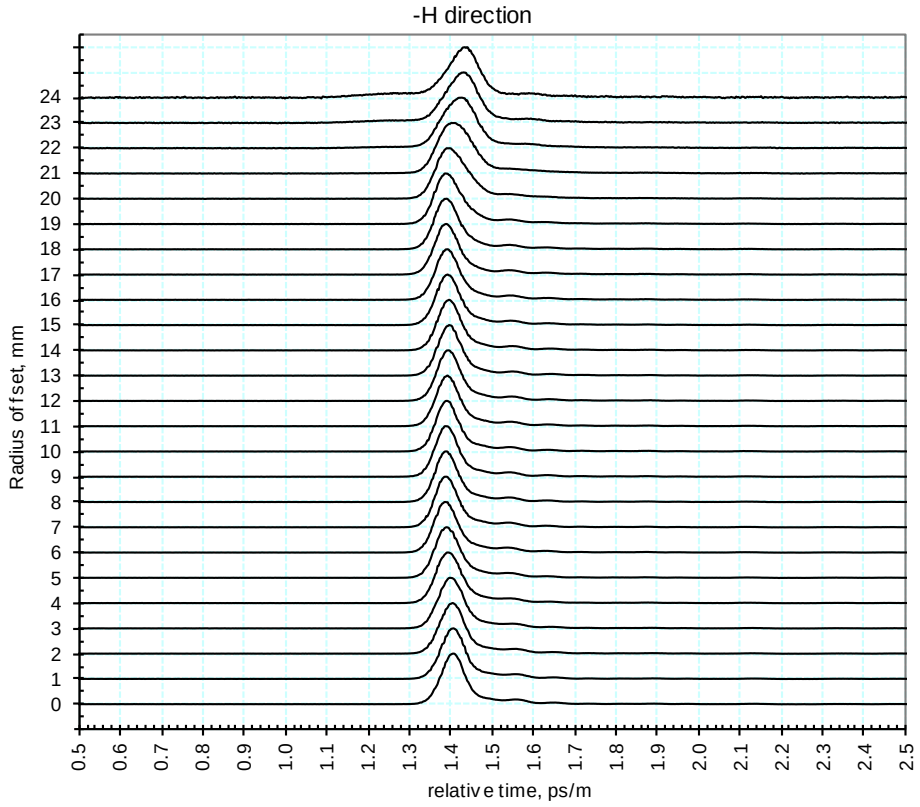
High Bandwidth MMF #A52, EMB = 12,183 MHz-km

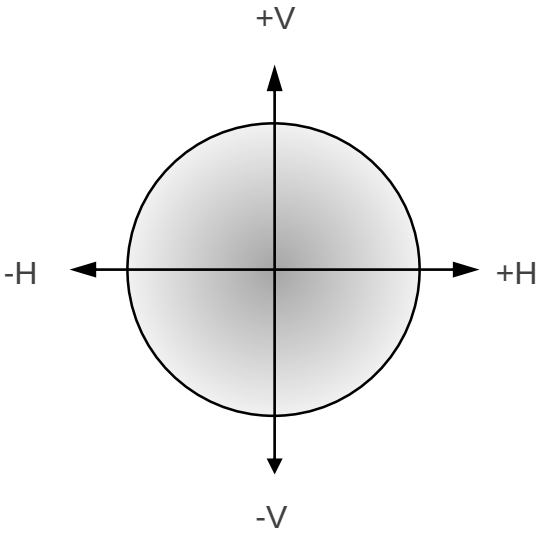
A52 849.95nm
3:21:15 PM, on 8/14/2013

Numerical results

	DMDouter	DMDinner	DMDsliding	OFLc	BERT EMBc	FOTP220 EMBc	Gaussian EMBc	% diff EMBc	FOTP220 EMB	Complies OM3*	Complies OM4*
-H	0.061	0.019	0.027	8270	7545	11268	0	100.0	12733	yes	yes
+H	0.057	0.021	0.024	8736	7931	11631	0	100.0	13143	yes	yes
-V	0.073	0.023	0.039	7582	6715	10002	0	100.0	11303	yes	yes
+V	0.076	0.024	0.043	7587	6553	10224	0	100.0	11554	yes	yes
mean	0.067	0.022	0.033	8044	7186	10781	0	100.0	12183	**yes**	**yes**
SD	0.009	0.002	0.009	563	660	791	0	0.0	893		

Pass EMBc (FOTP-220) consistency check? yes





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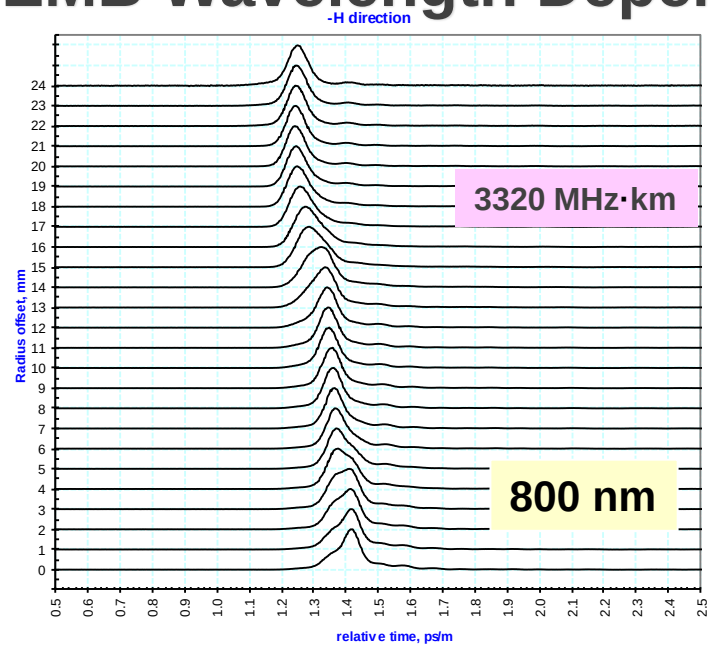
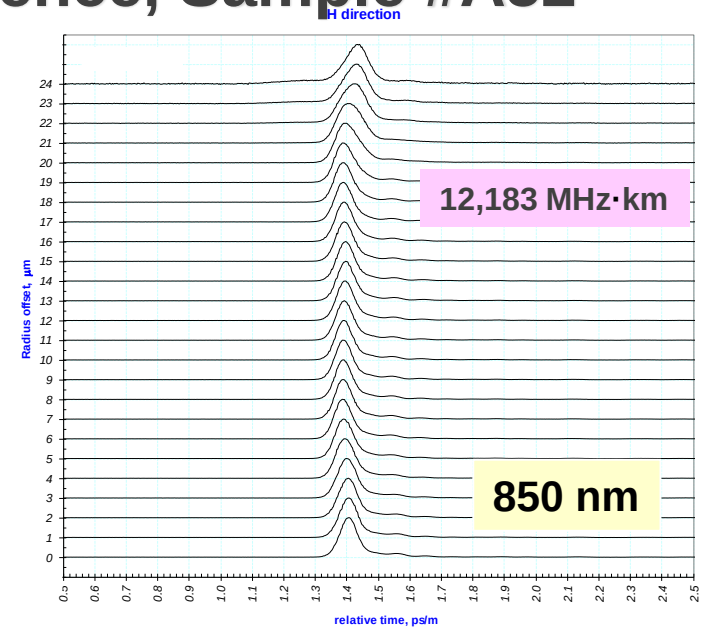
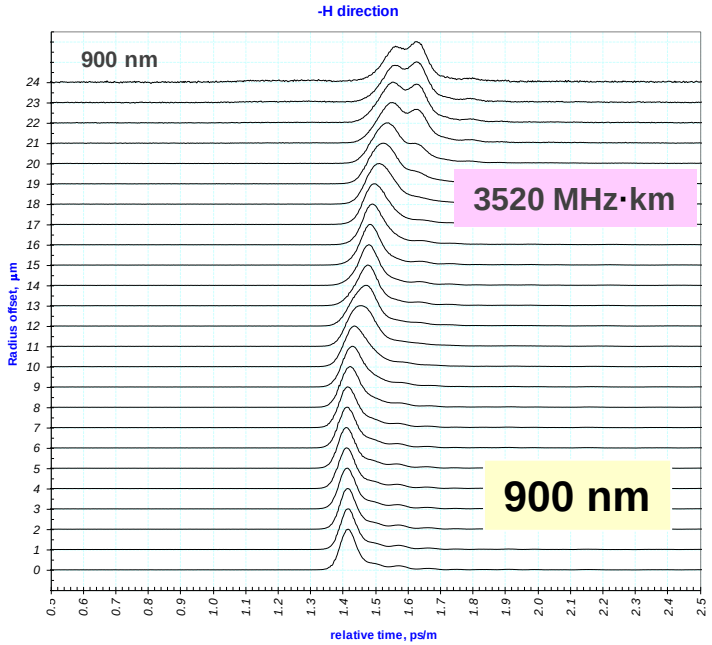
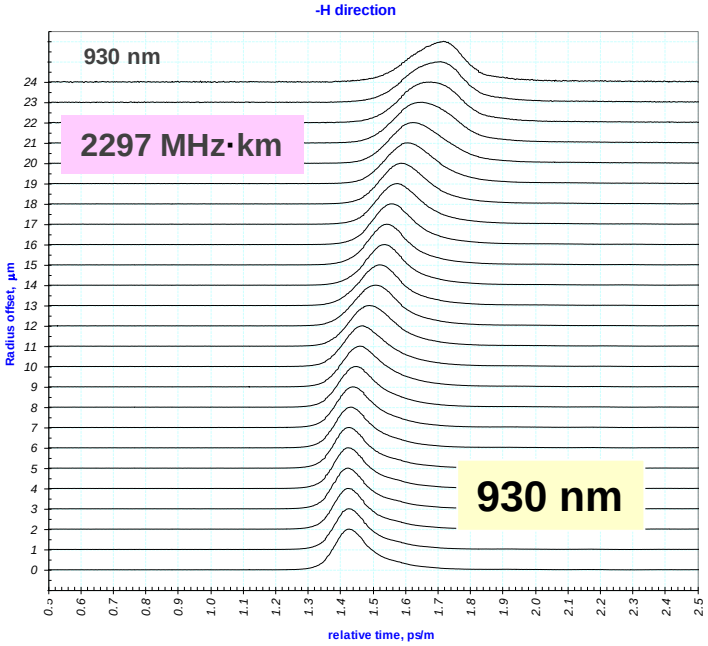
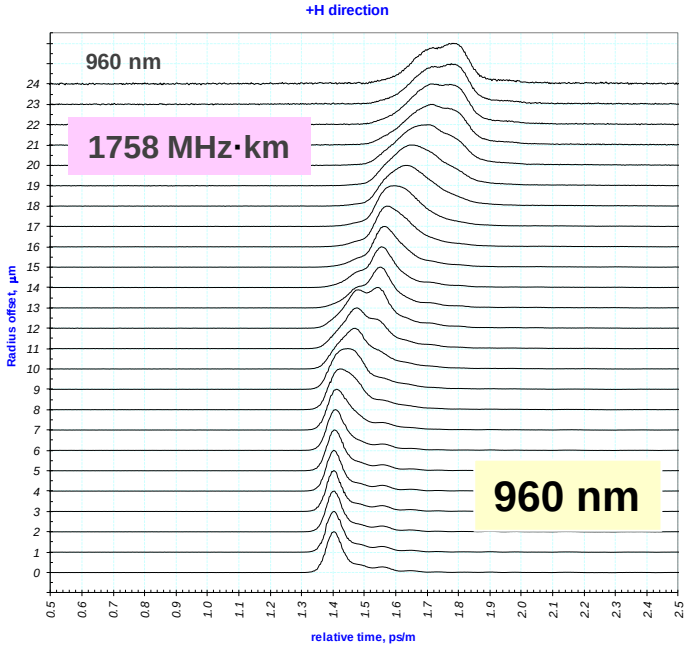
EMB Wavelength Dependence, Sample #A52

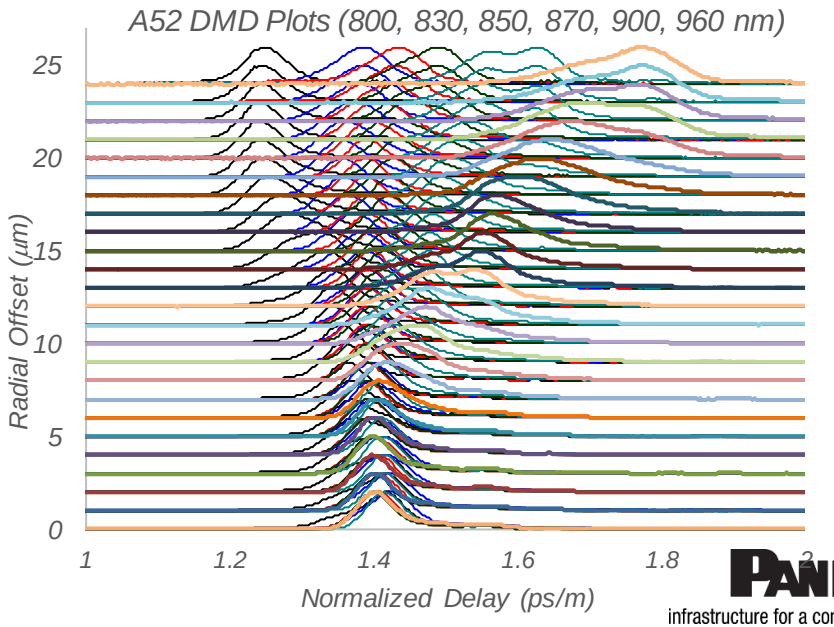












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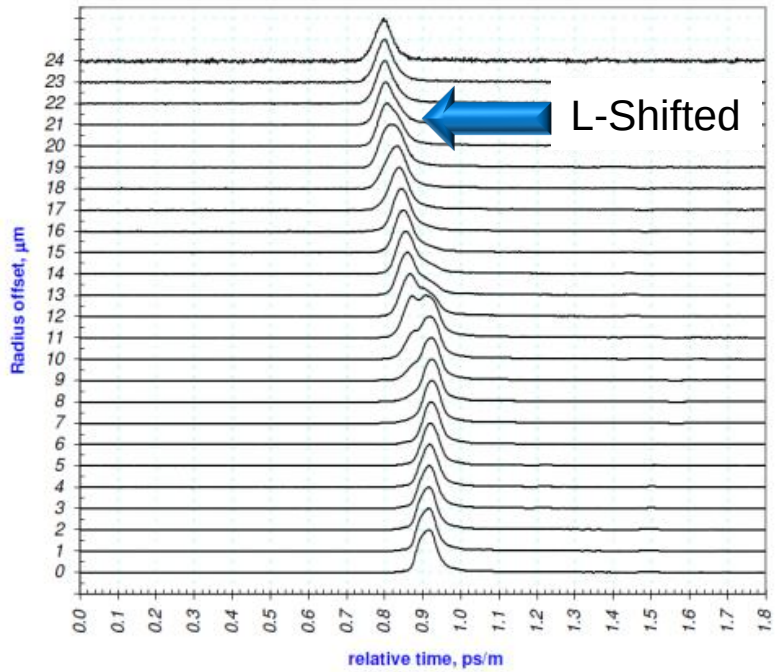
DMD Plots for two fibers with same bandwidth @ 850 nm

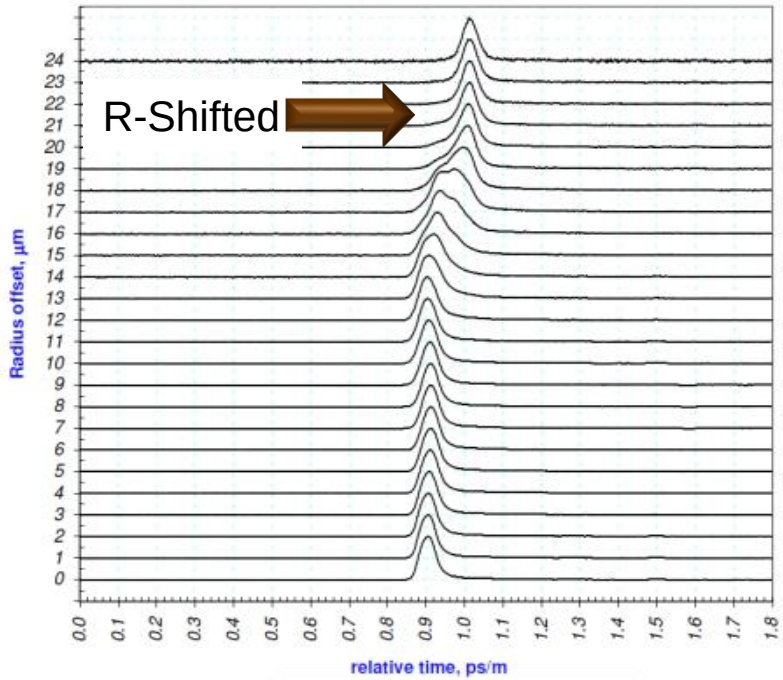
- *Two fibers from same cable with the same EMB (similar DMD)*
  - *L = 548 m*
  - *Ti:Sapphire Laser - DMD*

C26_Blue



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

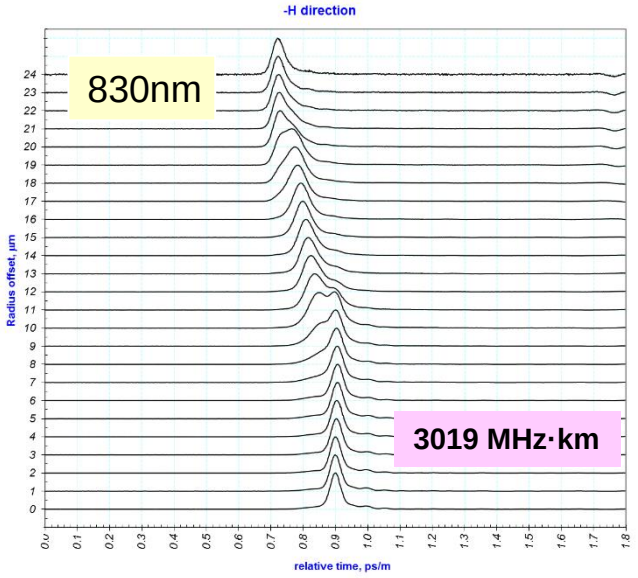
C26_Brown

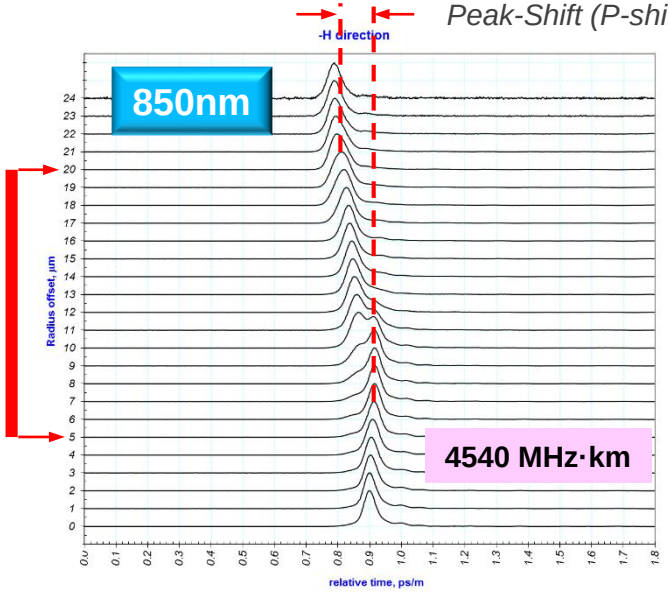


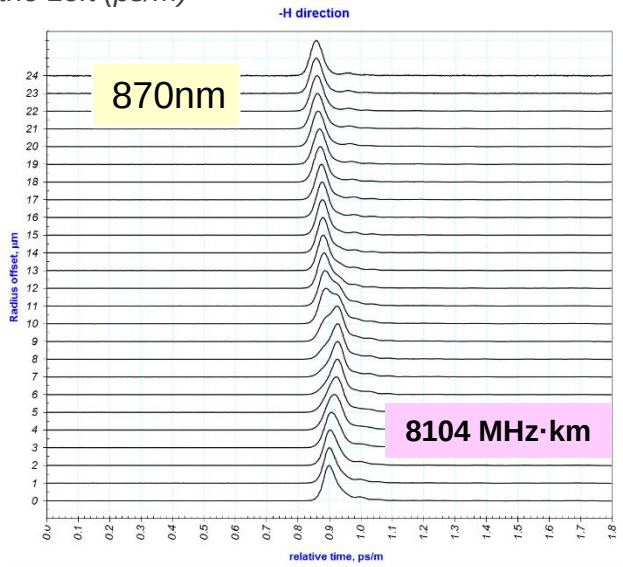
Brown Fiber
EMB = 4540 MHz·km
DMD_{inner} = 0.12 ps/m
DMD_{outer} = 0.13 ps/m
$DMD_{sliding}$ = 0.13 ps/m
DMD P-Shift = +0.096 ps/m

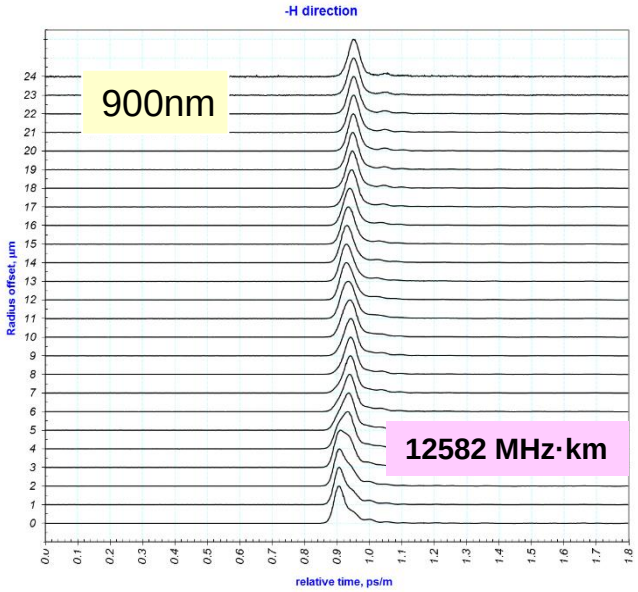
Fiber C26_Blue (OM3 Left-shifted at 850 nm)

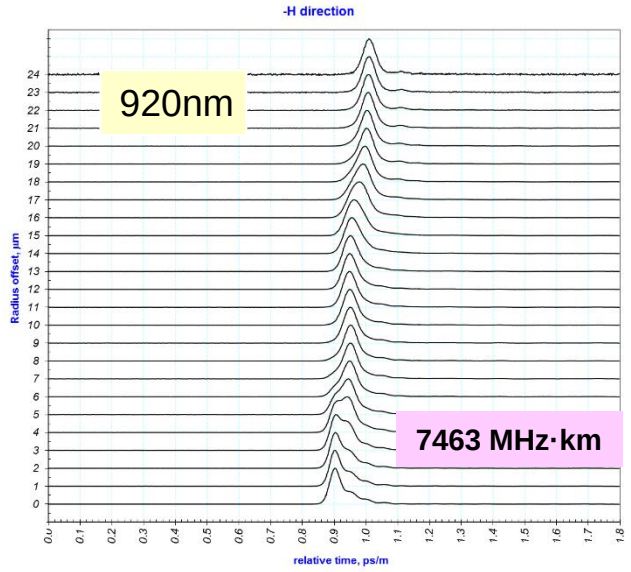
Peak-Shift (P-shift) to the Left (ps/m)

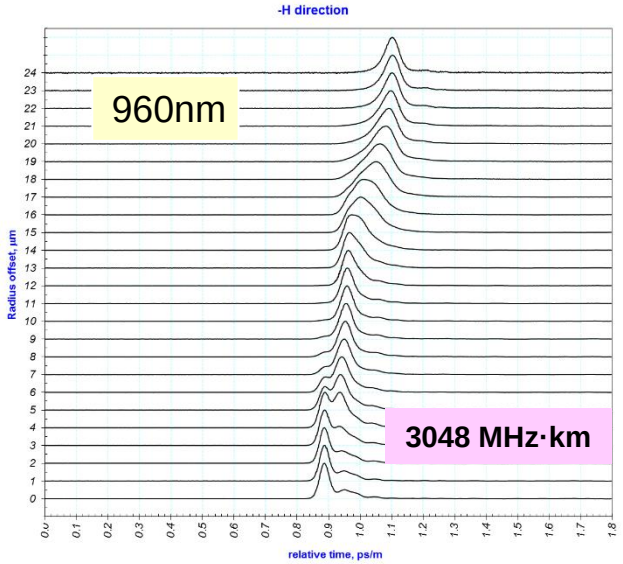




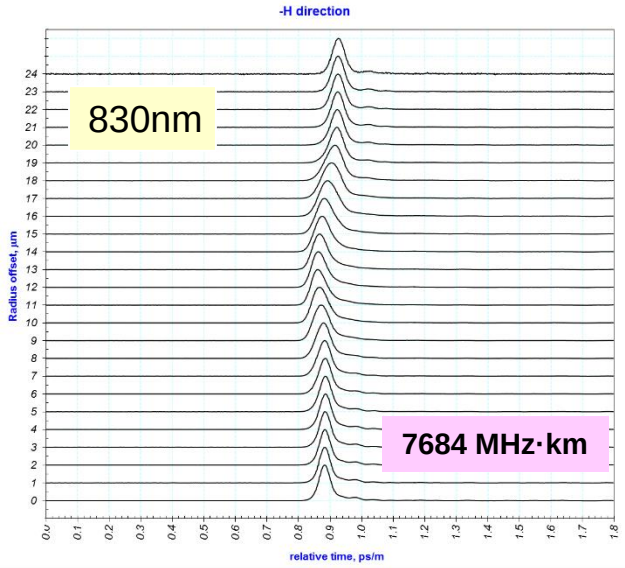


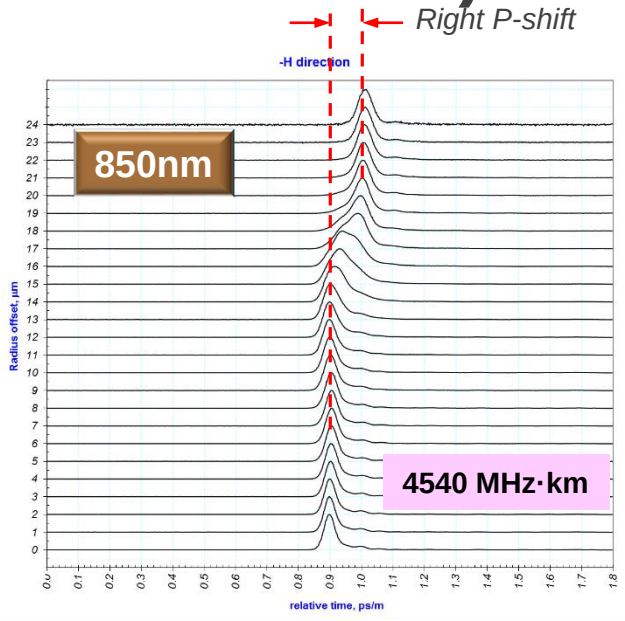


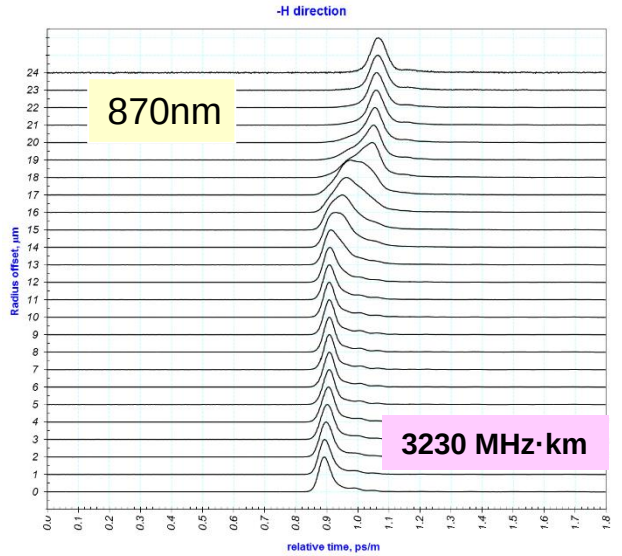


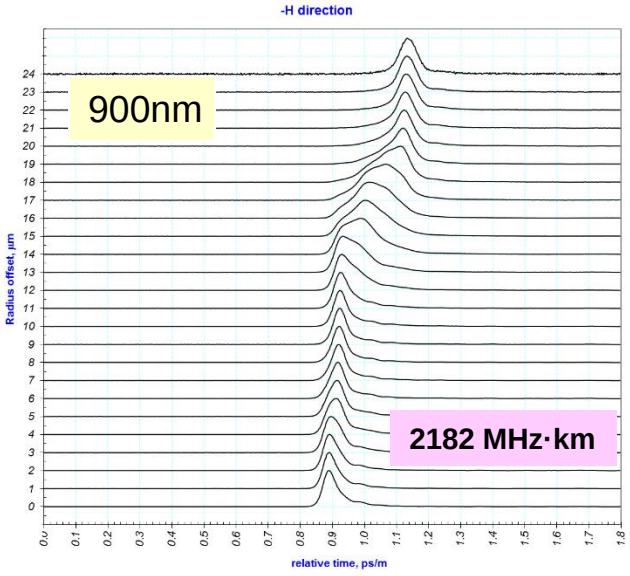


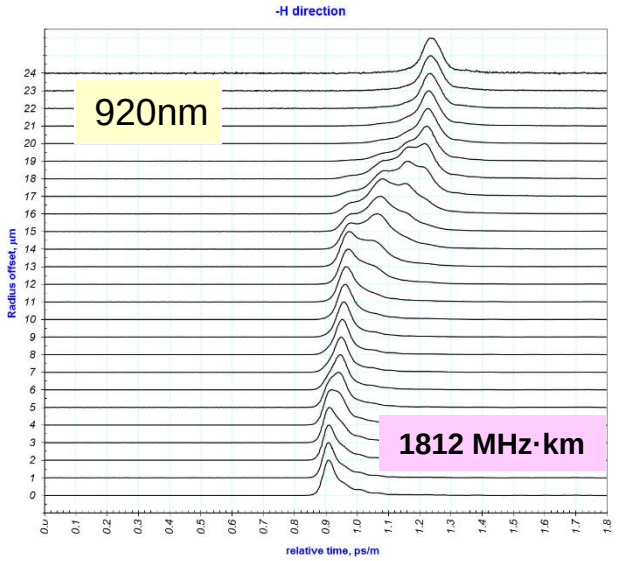
Fiber C26_Brown (Right-shifted 850 nm)

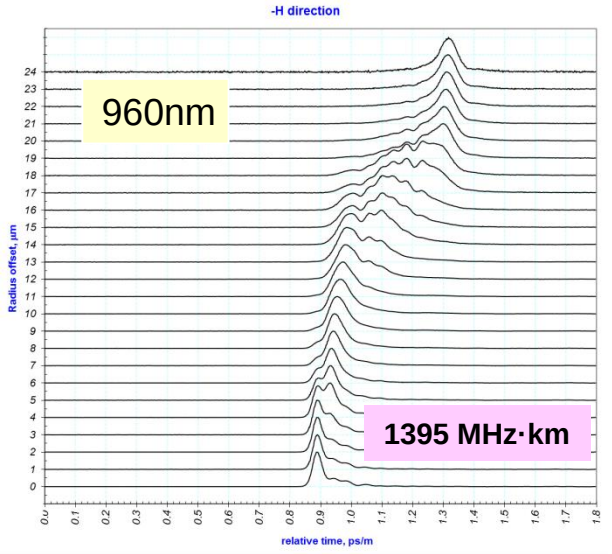






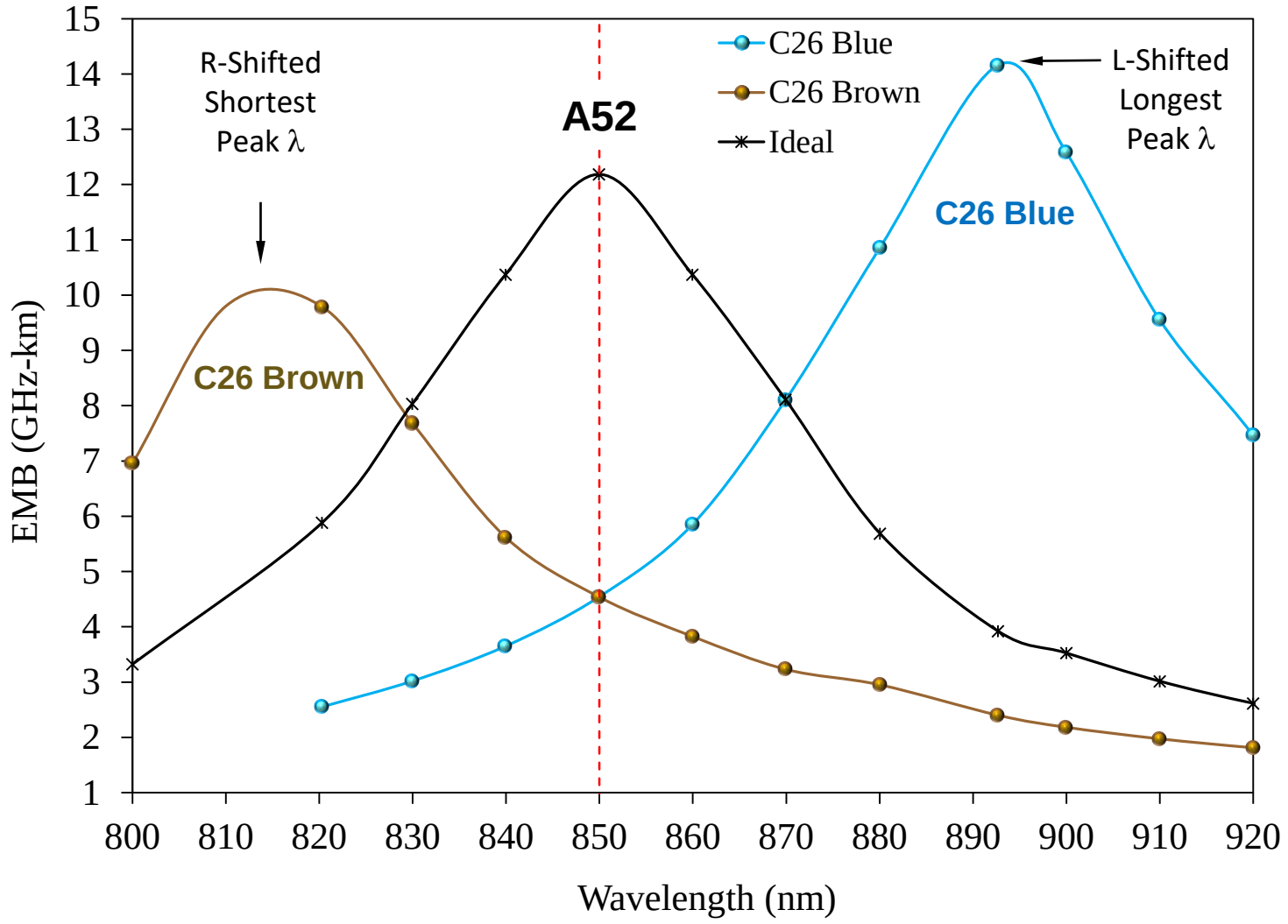




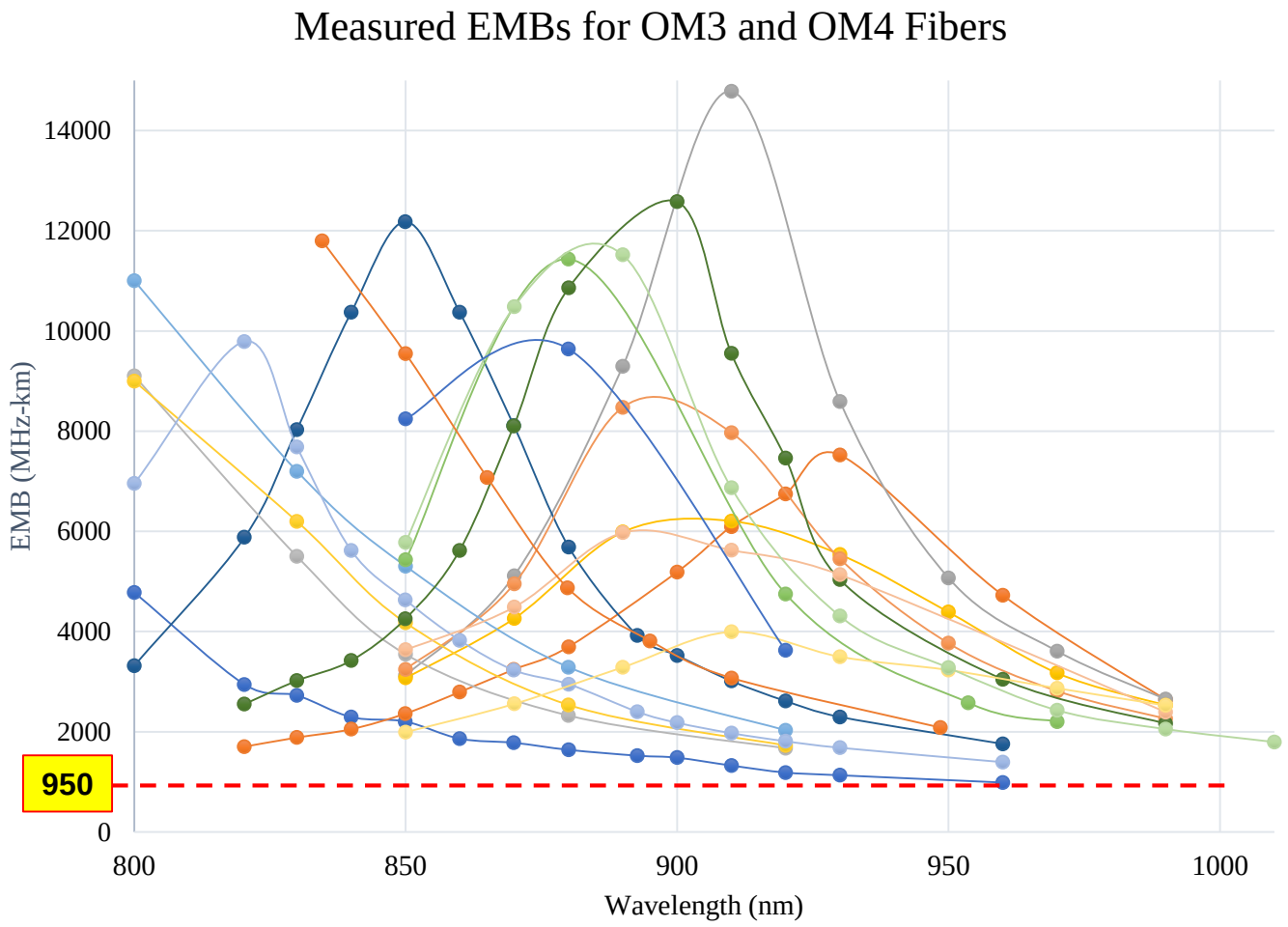


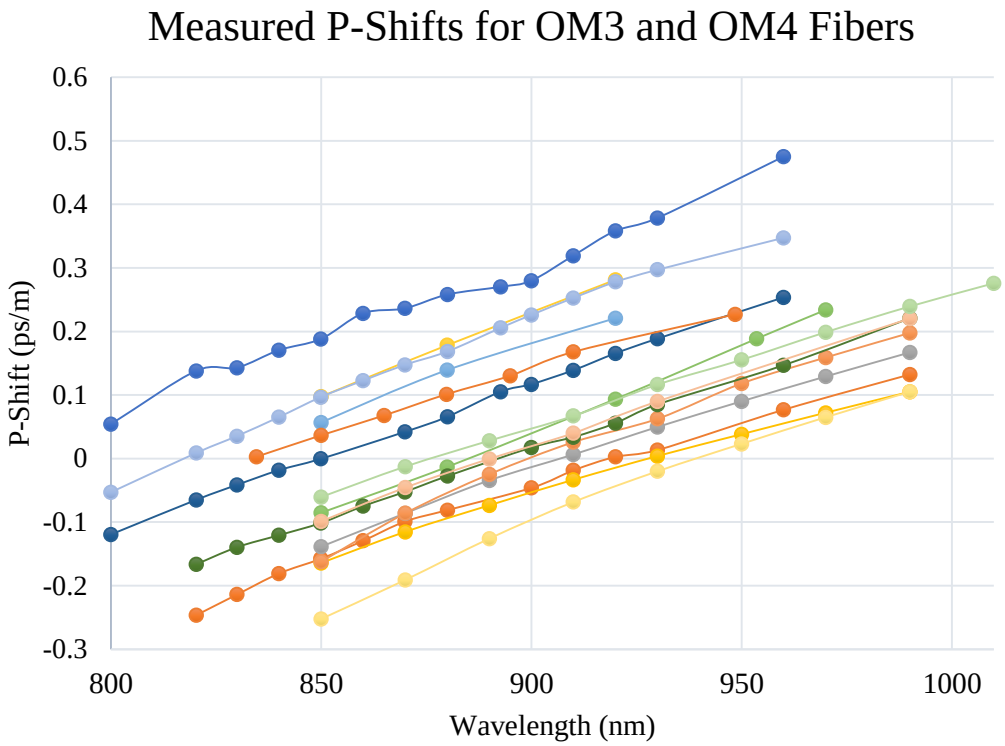
Range of EMB peak wavelengths for OM4 fibers

EMB wavelength dependence – Supplier C, same cable



EMB Wavelength dependence & its relationship to P-shift





P-Shift varies linearly with wavelength

Conclusion

1. The Effective Modal Bandwidth of multimode fiber is wavelength dependent
2. The specified EMB values for laser optimized OM3 and OM4 are for 850 nm VCSELs
3. If longer wavelength VCSELs are specified, the EMB will be lower
4. For a 980 nm VCSEL, the minimum EMB for OM3 is 950 MHz·km