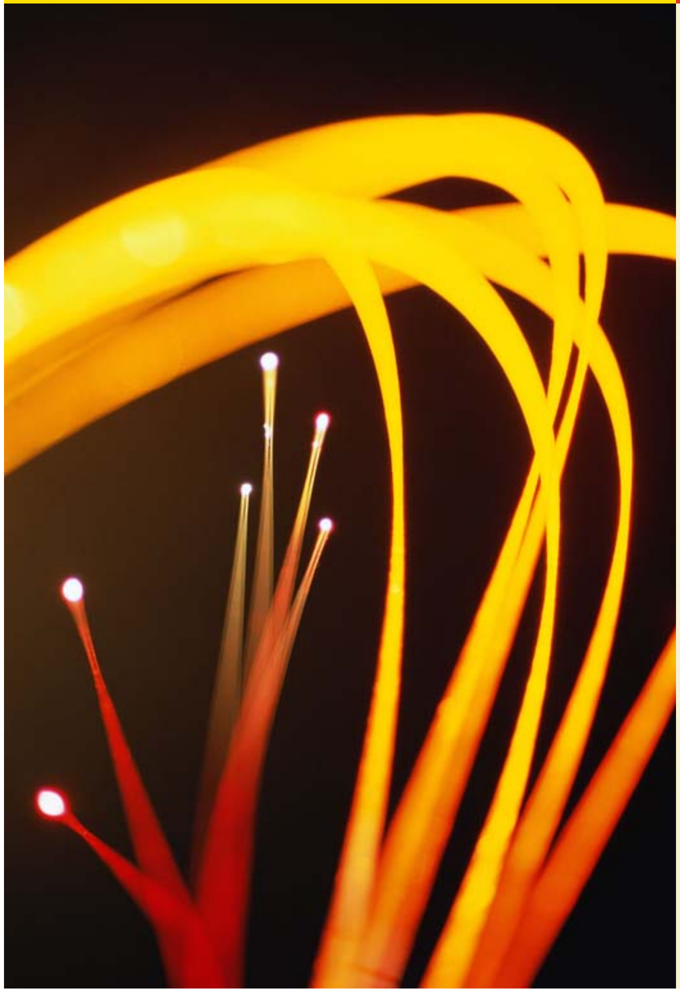

Bulk-Optics Dispersion Compensation

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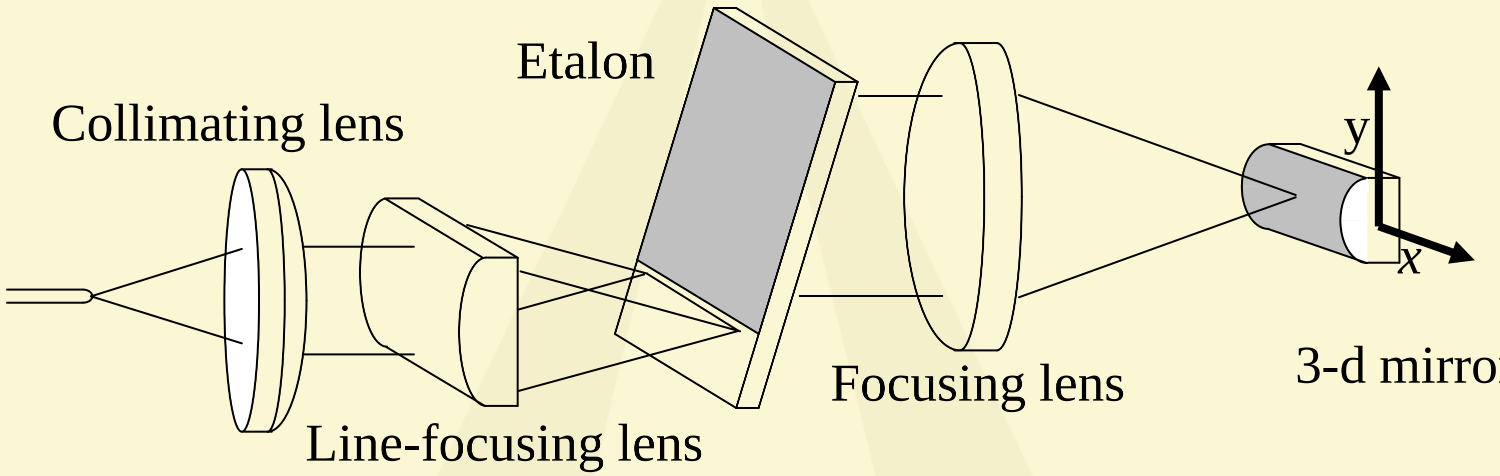
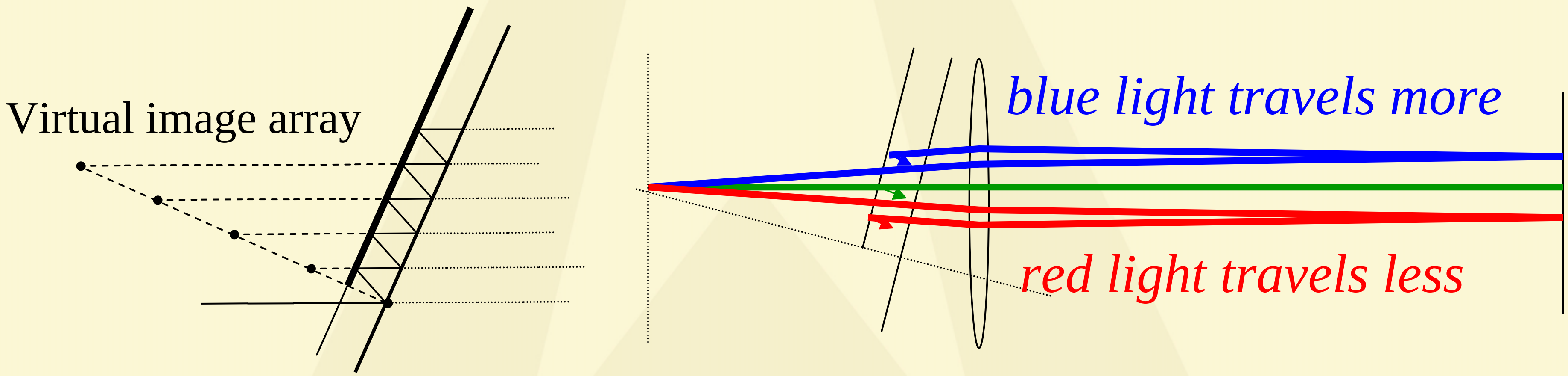
Outline

- Virtually Imaged Phased Array
  - Operation
  - Early Results
  - Recent Results and PMD
- All-pass filters
  - Cascaded Gires-Tournois etalons
  - Higher-order all-pass filters
- Comparisons

Virtually Imaged Phased Array

- **Inventor: Dr. Masataka Shirasaki**





M. Shirasaki, *Optics Letters*, vol. 21, no. 5, pp 366-368, 1996.

M. Shirasaki, *PTL*, vol. 9, no. 12, pp 1598-1600, 1997.

VIPA Early Results

- **“Demonstration of virtually-imaged phased-array device for tunable dispersion compensation in 16x10 Gb/s WDM transmission over 480 km standard fiber.”** L. D. Garret, A. H. Gnauck, M. H. Eiselt, R. W. Tkach, C. Yang, C. Mao, S. Cao. *Proceedings, OFC2000*, PD7.
- **“Variable Dispersion Compensator using the Virtually Imaged Phased Array (VIPA) for 40-Gbit/s WDM Transmission Systems.”** M. Shirasaki, Y. Kawahata, S. Cao, H. Ooi, N. Mitamura, H. Isono, G. Ishikawa, G. Barbarossa, C. Yang, C. Lin. *Proceedings, ECOC2000*, post-deadline paper.

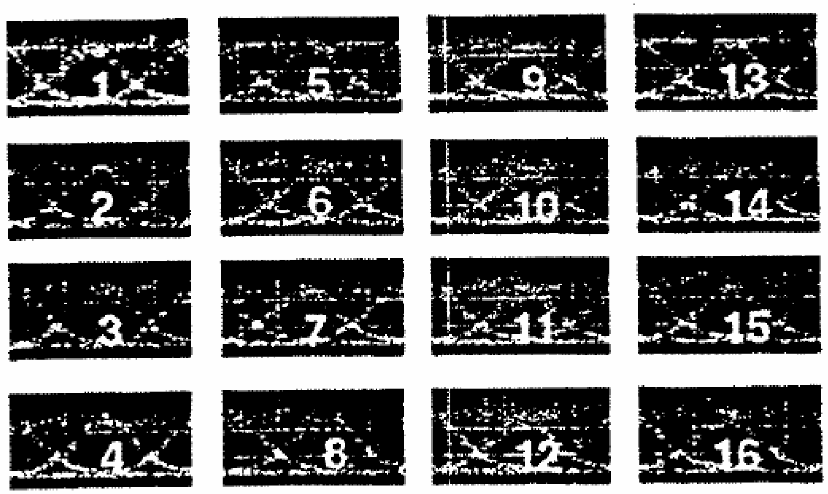


Figure 6: Eye diagrams for sixteen channels after 6 x 80km transmission for VIPA case showing uniform shape.

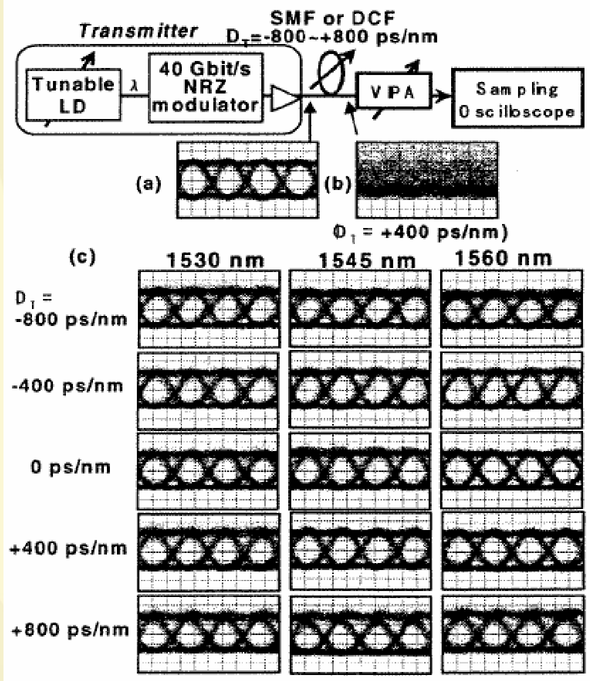
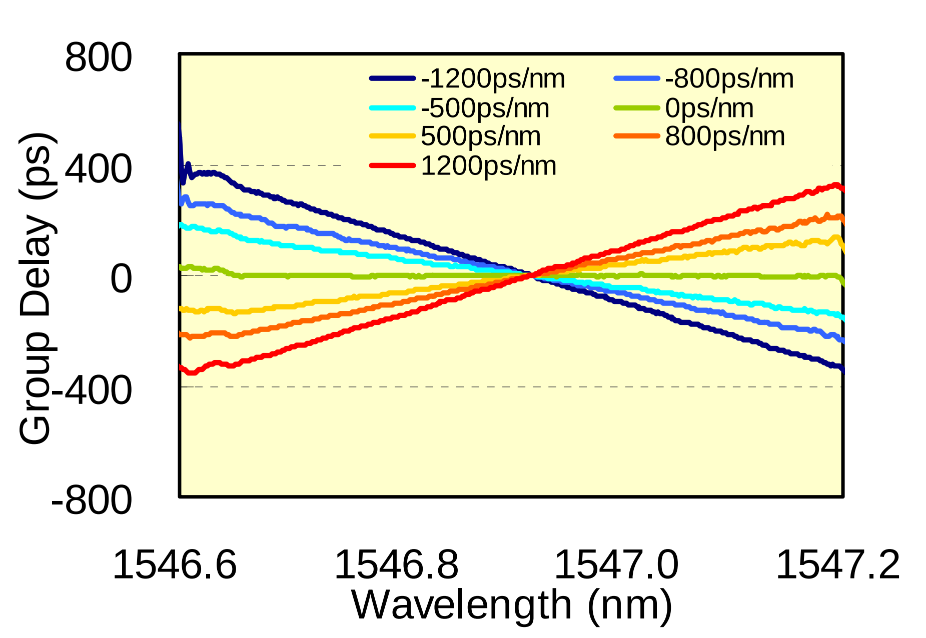


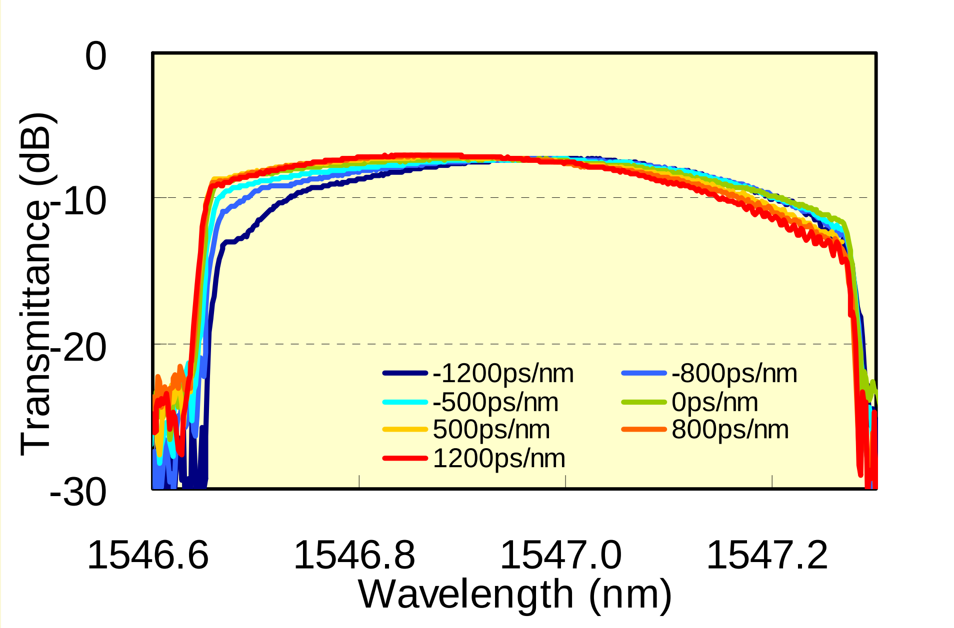
Fig. 5 40-Gbit/s optical waveforms. (H: 10 ps/div.)

VIPA 40 Gbps Results

Group delay



Transmittance



Characteristics of VIPA module

(100 GHz Spacing, -1200 ～ +1200 ps/nm)

Courtesy of Fujitsu

VIPA with SLM Instead of Mirror

- Use LC array instead of machined, sliding mirror for phase manipulation.

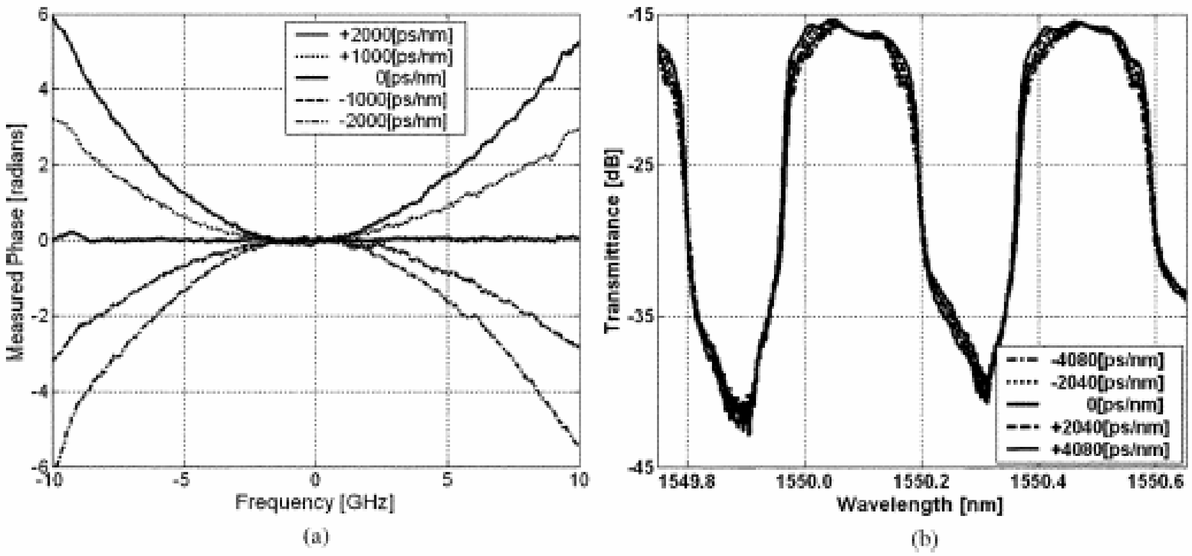
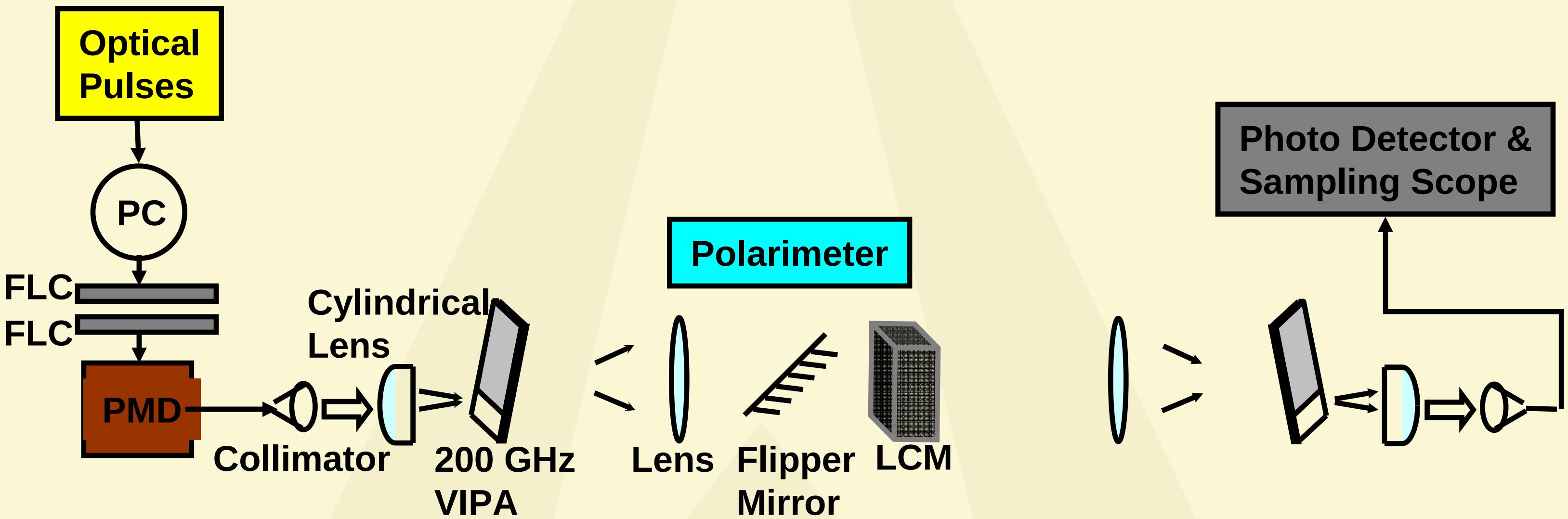


Fig. 2. (a) Measured phase with different dispersion settings (from −2000 to +2000 ps/nm) for TDC. (b) TDC transmission spectra with different dispersion settings (from −4080 to +4080 ps/nm).

"Optical Dispersion Compensator with >4000-ps/nm Tuning Range Using a Virtually Imaged Phased Array (VIPA) and Spatial Light Modulator (SLM)." Ghang-Ho Lee, Shijun Xiao, Andrew M. Weiner, *PTL*, vol. 18, no. 17, pp 1819-1821, 2006.

VIPA and PMD

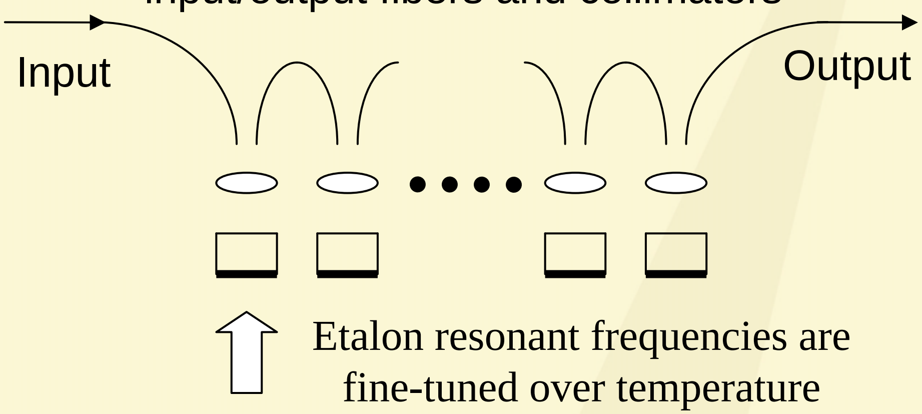
- Thursday morning at OFC, 8-9 AM, "PMD Compensation at Ultra-High Bit Rates," Andrew Weiner, Purdue University, Room 6F.
- Thursday morning at OFC 9:00 AM, "All-Order PMD Compensation via VIPA Based Pulse Shaper," Houxun Miao, et al., Room 6F.

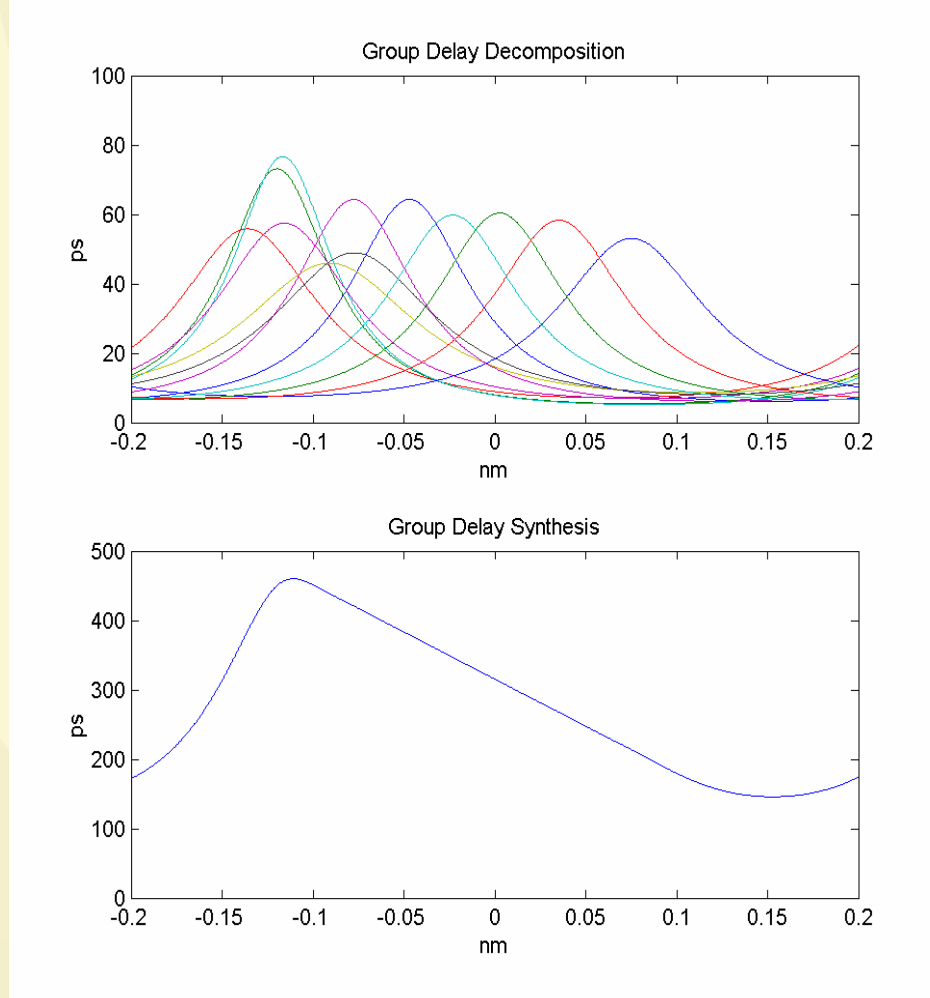


"All-Order PMD Compensation via VIPA Based Pulse Shapers," [INVITED], *H. Miao* and A. M. Weiner, 20th IEEE/LEOS Annual Meeting, Lake Buena Vista, FL, October 21-25, 2007

Cascaded Gires-Tournois Etalons

Cascaded all-pass filters with input/output fibers and collimators

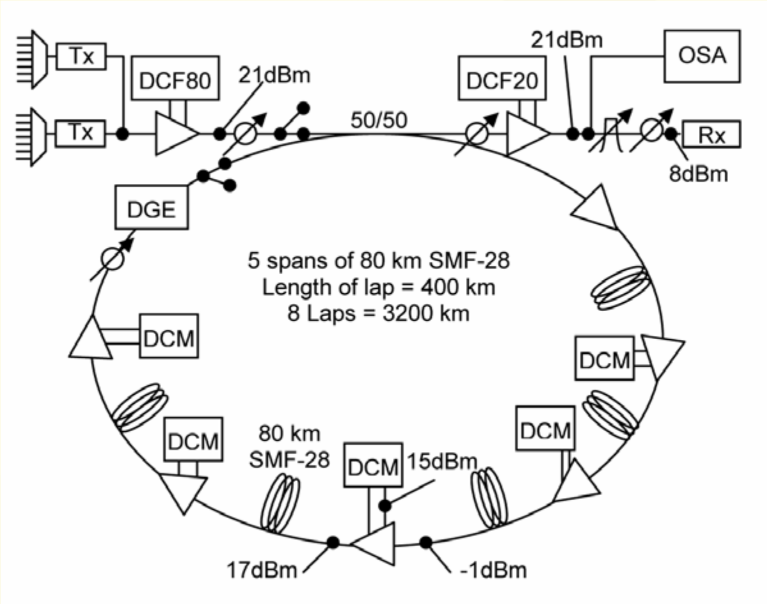


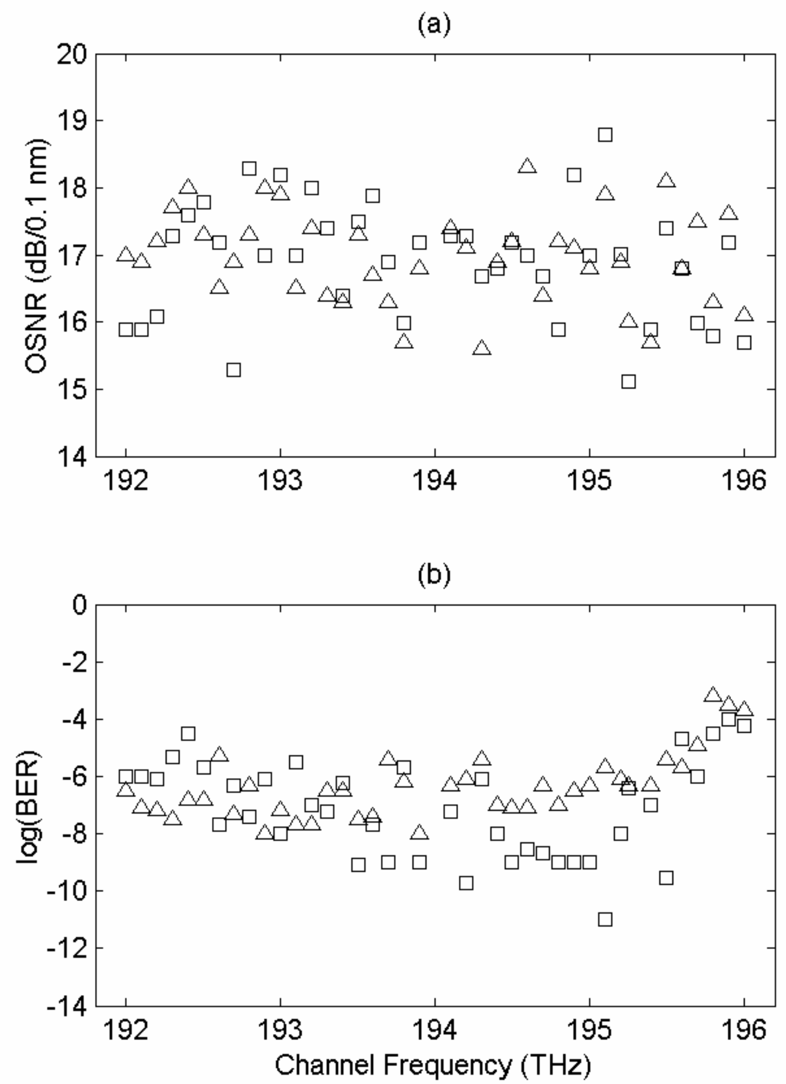


- **"Tunable Dispersion Compensator Using Cascaded Gires-Tournois Etalons."** D. Yang, W. Zhu, W. Chen, C. Lin, G. Barbarossa, ECOC 2003.

Fixed System Level Results

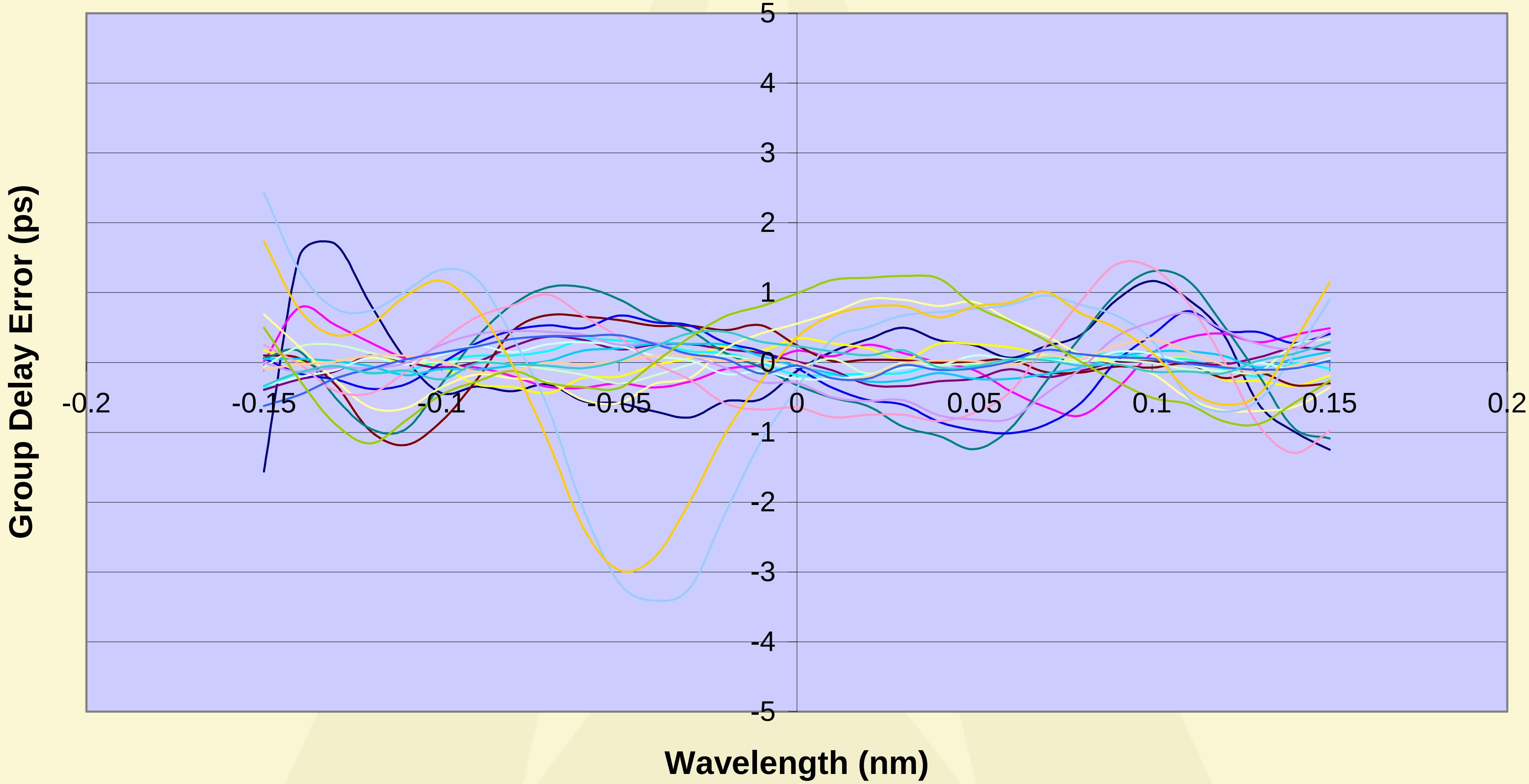
- **"Fiber dispersion and dispersion slope compensation in a 40-channel 10-Gb/s 3200-km transmission experiment using cascaded single-cavity Gires-Tournois etalons."** D. Yang, C. Lin, W. Chen, G. Barbarossa. *PTL*, January 2004, volume 16, number 1, pp 299-301.
- System measurements courtesy of Alcatel-Lucent.





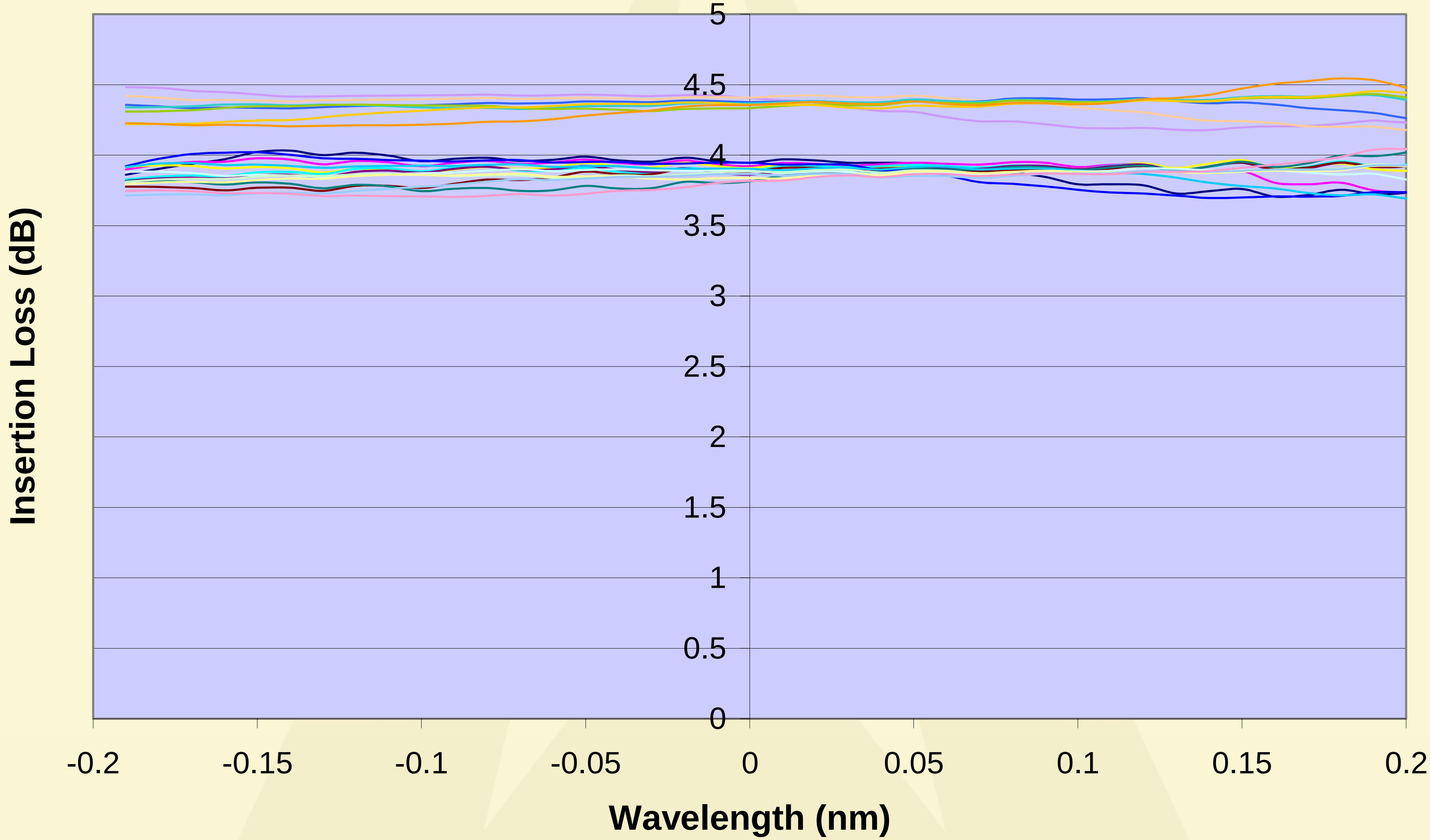
Group Delay Ripple

+/- 700 ps/nm, 1527.2 nm, 1545.3 nm, and 1565.5 nm



Insertion Loss

+/- 700 ps/nm, 1527.2 nm, 1545.3 nm, and 1565.5 nm



Higher-Order All-Pass Filters

- **"Tunable Dispersion and Dispersion Slope Compensators for 10 Gb/s Using All-Pass Multicavity Etalons."** D.J. Moss, M. Lamont, S. McLaughlin, G. Randall, P. Colbourne, S. Kiran, C.A. Hulse. *PTL,* vol. 15, no. 5, May 2003.

TABLE I
SPECIFICATIONS OF 50- AND 100-GHz DEVICES FOR 10 Gb/s

FSR (GHz)	Band	Reflections (A/B)	Frequency Range (THz)	BW (GHz)	Dispersion Tuning Range (ps/nm)	GDR (ps)	Loss (dB)
50	C	2/2	192-196	25	+/- 800	+/- 4.0	4.4
50	L	4/4	187-191 (185-192)	25	+1700 / -1500	+/- 5.7 (+/- 7)	8.2 (8.3)
100	C	2/4	192 -196	30	+/- 500	+/- 3.0	5.3

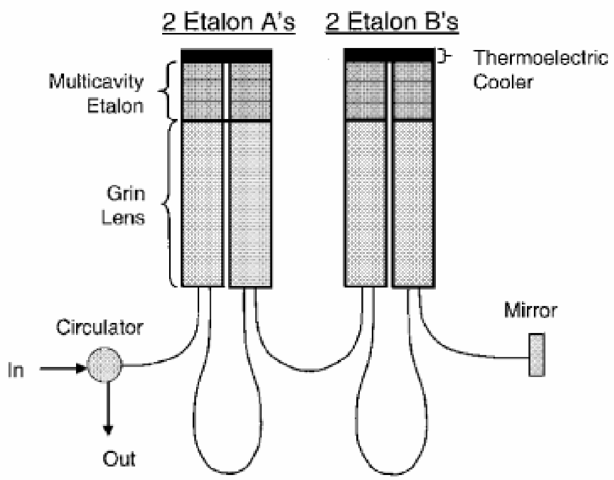


Fig. 2. Optical coupling configuration for the 50-GHz *L*-band device, employing two etalon As, two etalon Bs, and a mirror–circulator to double the number of passes.

number of etalons) which would normally be weighed against the introduction of the circulator loss (1.5 dB).

The scaling rules for this device are generic to etalon filters and are discussed at length elsewhere [8]. Briefly, the de-

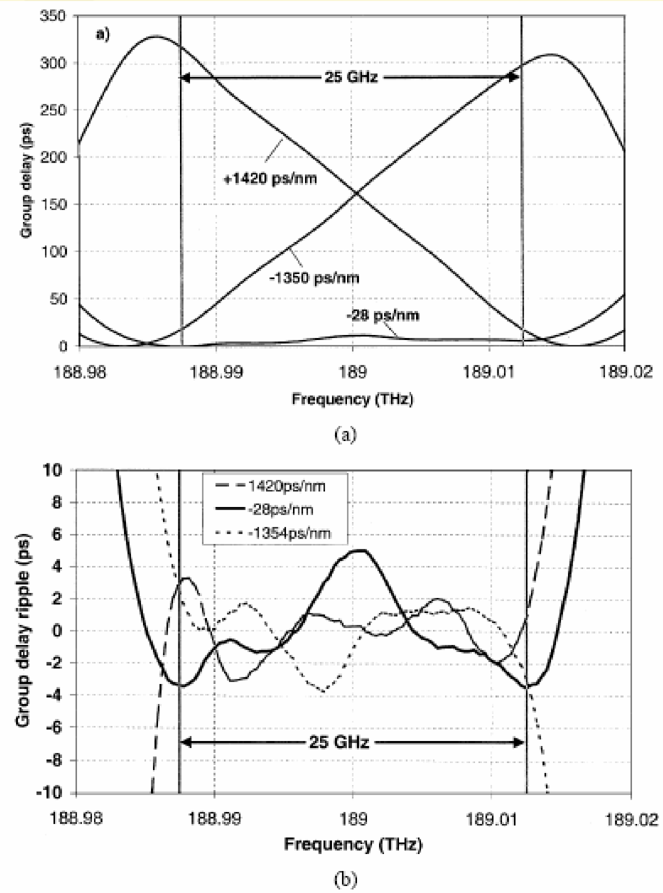


Fig. 3. (a) Group delay and (b) GDR of 50-GHz *L*-band device over the 189-THz channel for several dispersion settings. The GDR was obtained by subtracting a linear fit over a 25-GHz bandwidth of the group delay.

Comparisons

	VIPA	Cascaded G-T	Higher-order all-pass filters
Etalon Manufacture	Difficult: input window edge quality, FSR consistency over a large area.	Easy	Difficult: must have very good FSR match among the multiple cavities.
Tuning	3d mirror: hard LC array: ok	Thermal tuning: easy	Thermal tuning: easy
Specifications	Contact Fujitsu, Ltd.	Contact Avanex, Inc.	Not offered commercially.