Photonic time-stretching of 102 GHz millimeter waves using 1.55 μm nonlinear optic polymer EO modulators

H. Erlig

Pacific Wave Industries

H. R. Fetterman and D. Chang

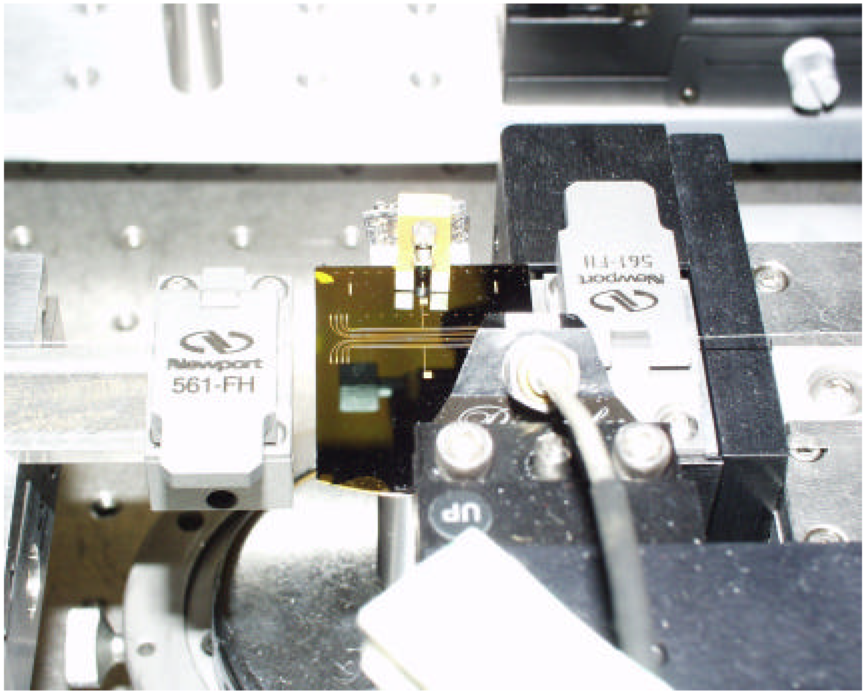
University of California Los Angeles

M. Oh, C. Zhang, W. H. Steier, and L. R. Dalton

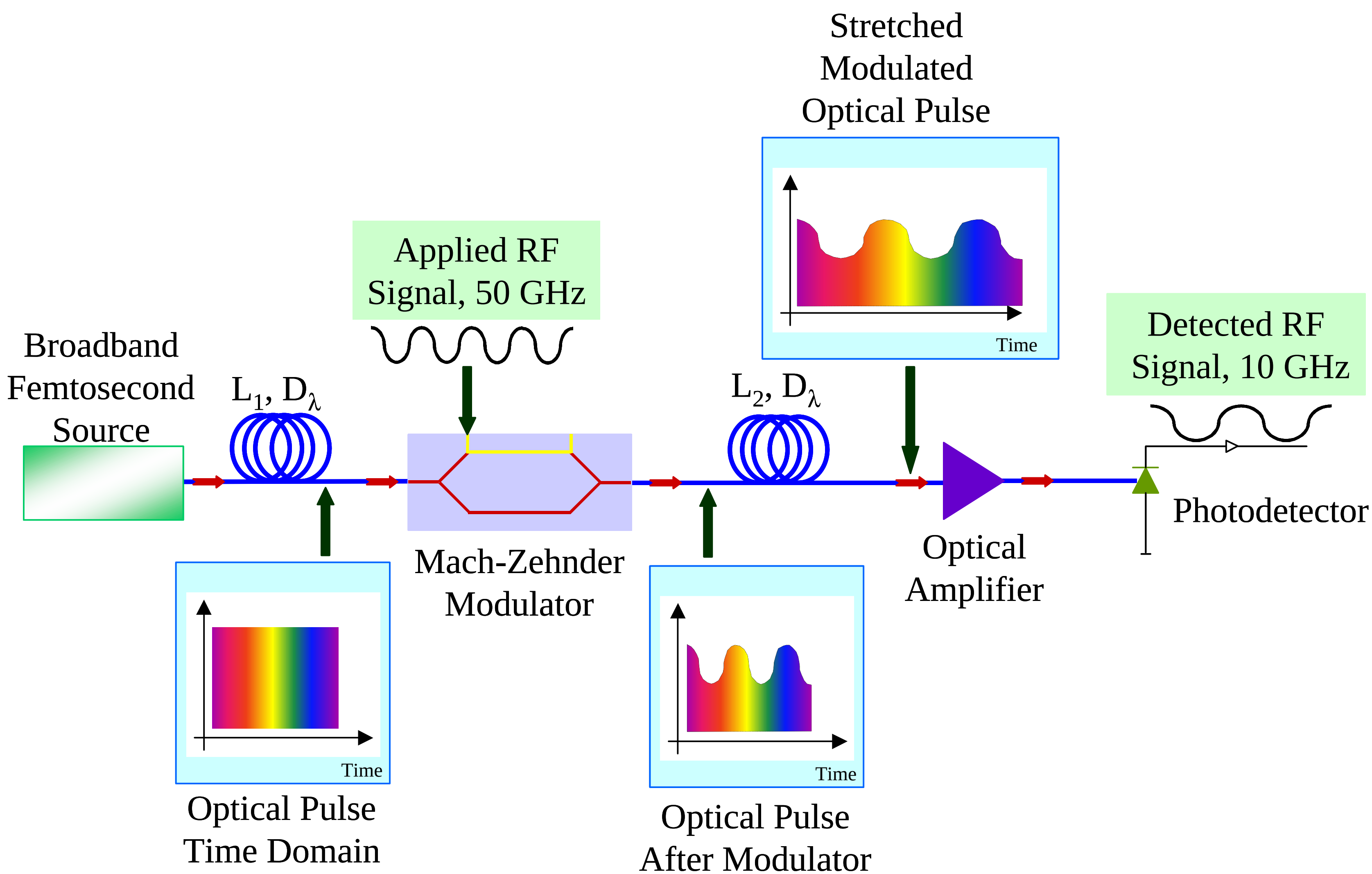
University of Southern California

Outline

- Time-stretch concept
- Experimental description
- Polymer modulator
- Data and data analysis
- Dispersion penalty & SSB modulation
- Conclusions



Time-Stretching Concept



Time-Stretching - Intensity

$$I(t) \propto f(t) \cos\left(\frac{2\pi f_m}{M} t\right) \cos\left(2\pi^2 \frac{\beta'' L_2}{M} f_m^2\right)$$

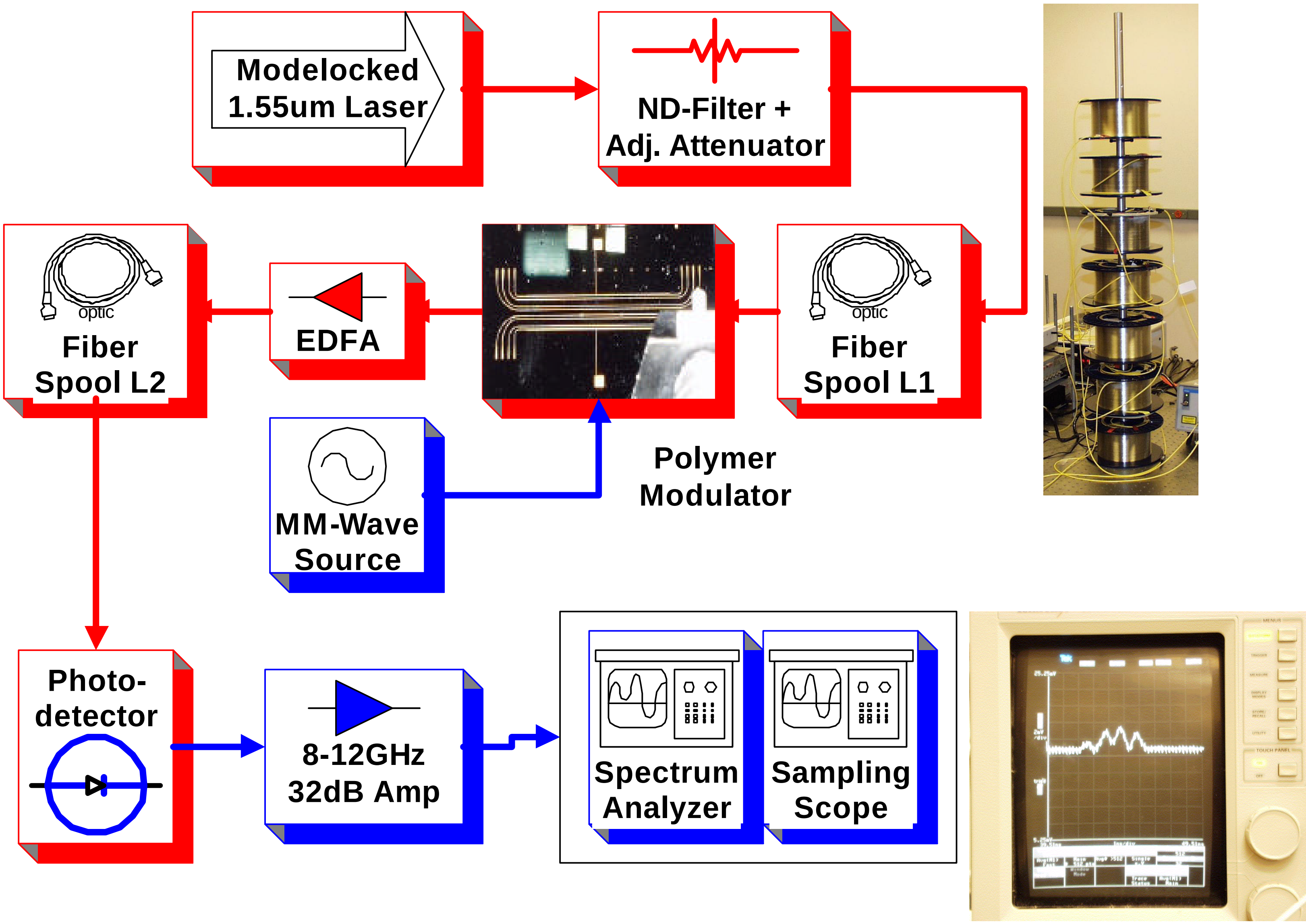
$f(t)$: Pulse Envelope

$\cos\left(\frac{2\pi f_m}{M} t\right)$: Time-Stretched Waveform

$\cos\left(2\pi^2 \frac{\beta'' L_2}{M} f_m^2\right)$: Dispersion Penalty, Leads to amplitude attenuation

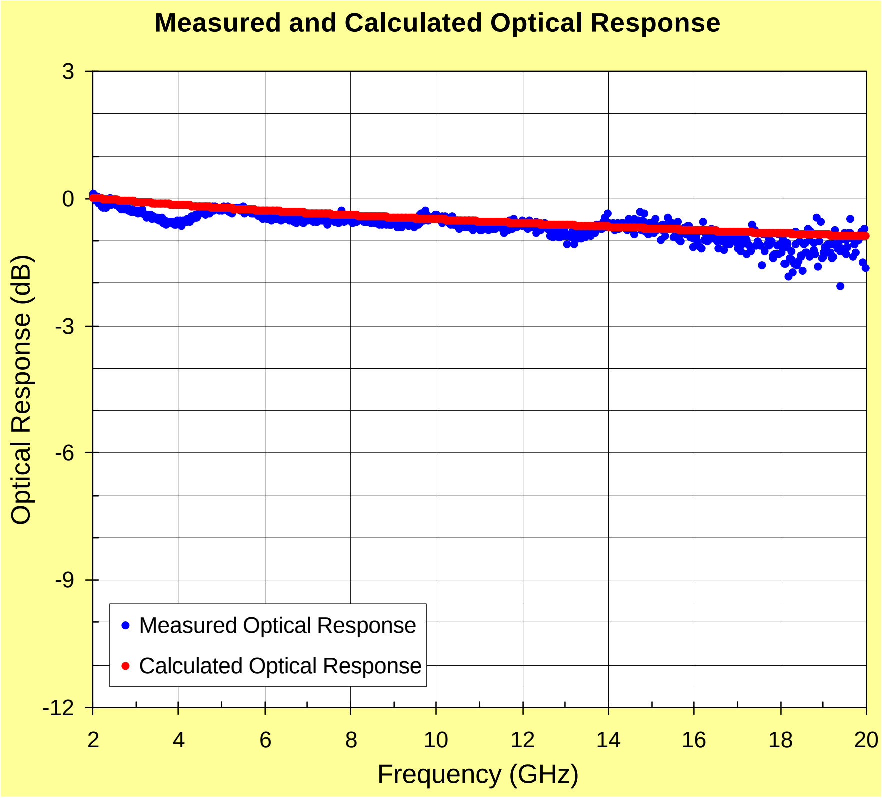
$$M = 1 + \frac{L_2}{L_1}$$ Stretch Ratio

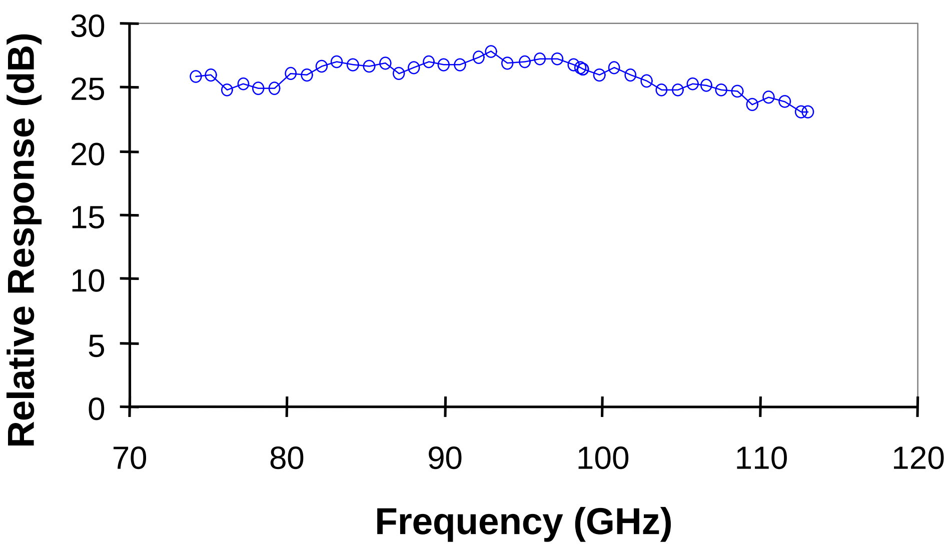
Experimental Arrangement



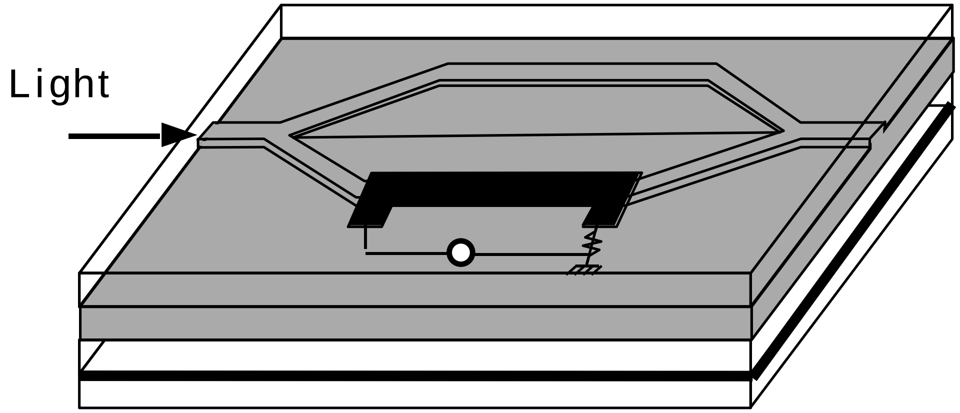
Polymer Modulator

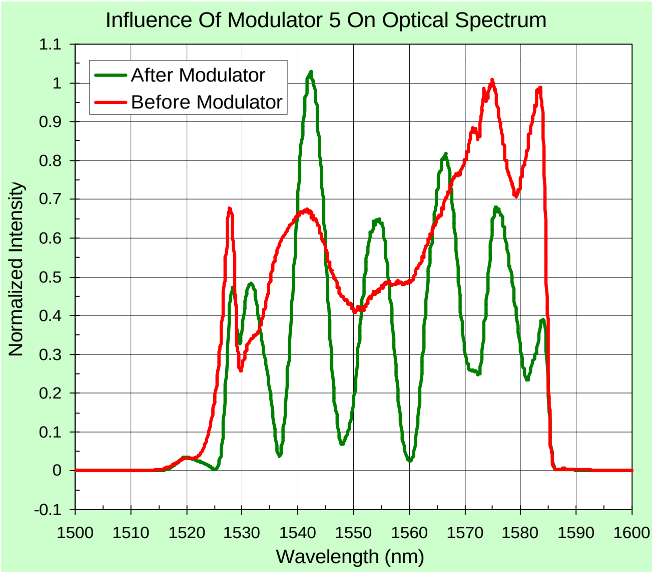
- PC/CLD polymer traveling wave modulators
- Optical network analyzer: 1 dB down at 20 GHz compared to 2 GHz
- Modeled effects: velocity mismatch and electrical loss
- V_{π} ~ 7 V, 1.3 cm interaction length
- W-band response relatively flat



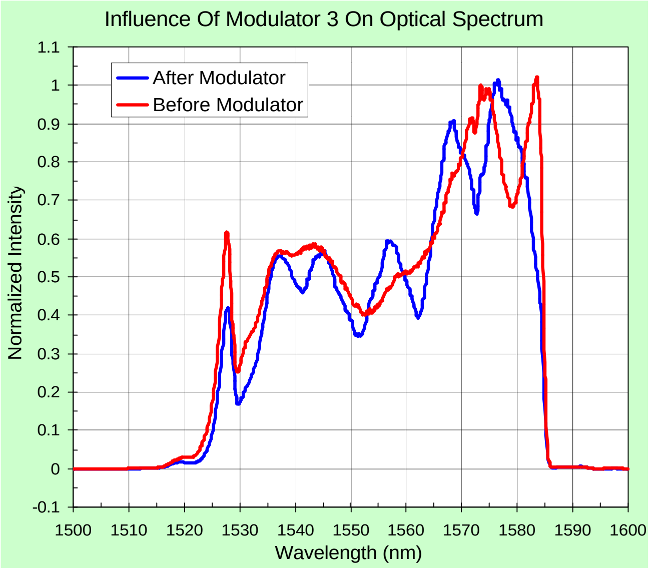


Transmission Through Modulator

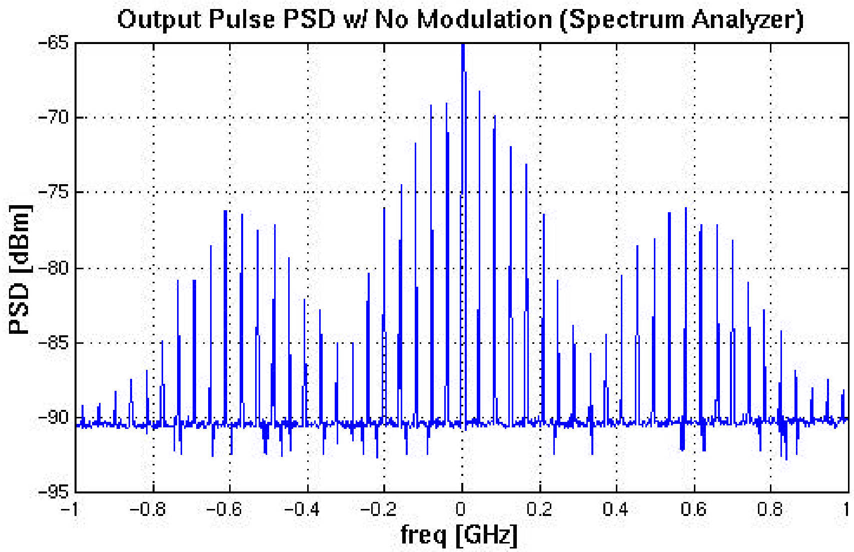


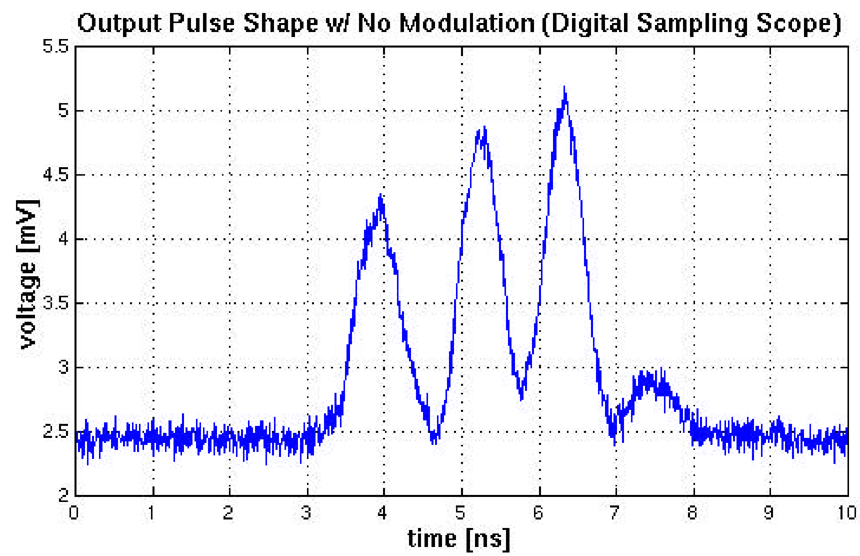


- Mach-Zehnders used with broadband femtosecond source
- Modulators reshape 50 nm spectrum
- Different modulators on chip introduce different amount of spectral reshaping
- Slight optical path mismatch
- Highly chirp pulses key
- Effect also observed in $LiNbO_3$ modulators



Pulse Shape After System





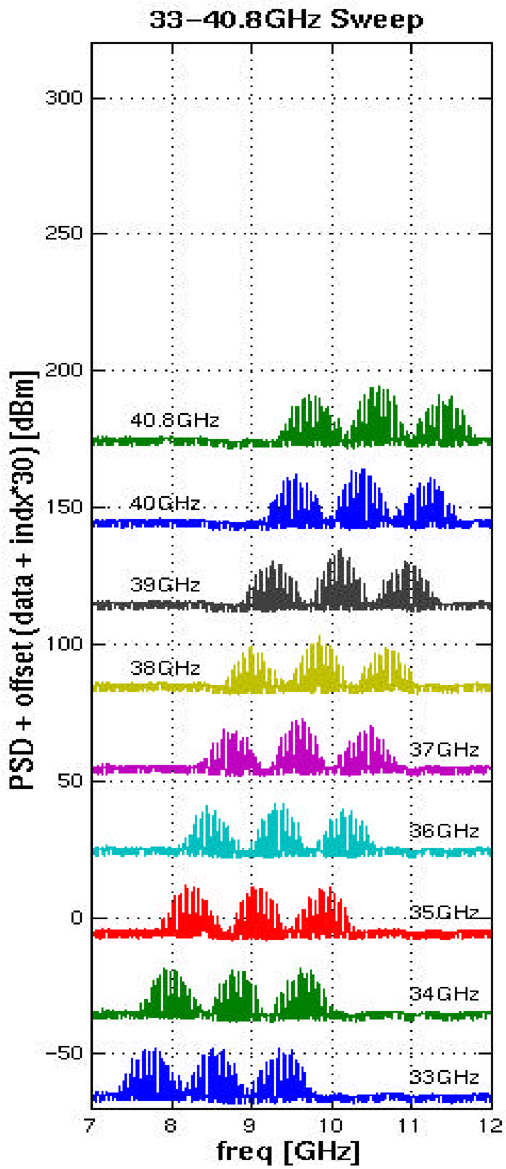
- Two interfering highly chirped optical pulses

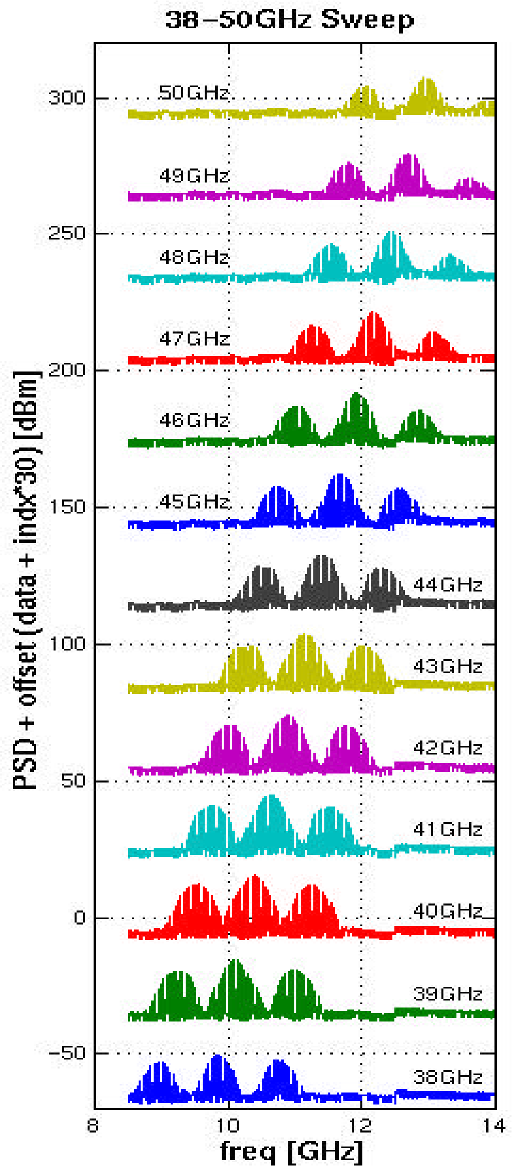
$$I(t) \propto \exp\left(\frac{-t^2}{\left(\beta'' L / T_0\right)^2}\right) \cdot \cos^2\left(\frac{1}{2} b \frac{\delta z}{c} t\right)$$

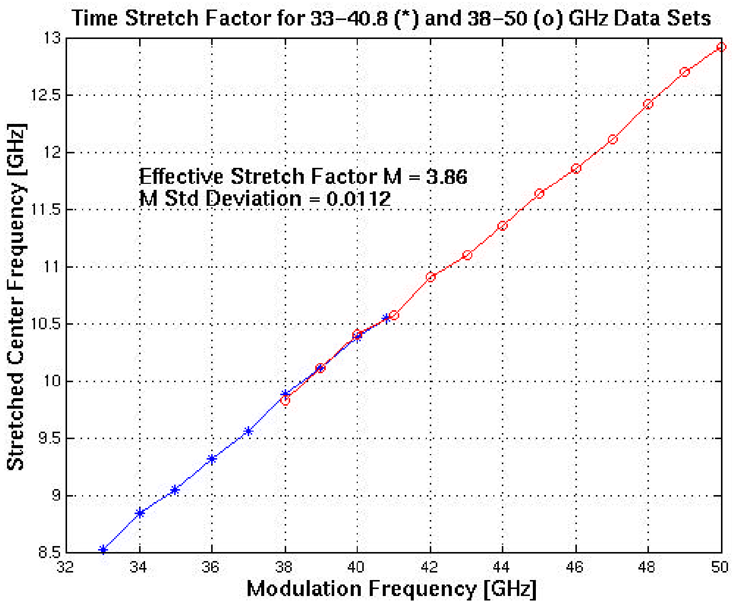
For system parameters and period of 1.5 ns

- Calculated effective optical path mismatch of 100 µm
- Calculated effective index mismatch 0.005

33 To 50 GHz Time-Stretched Signals



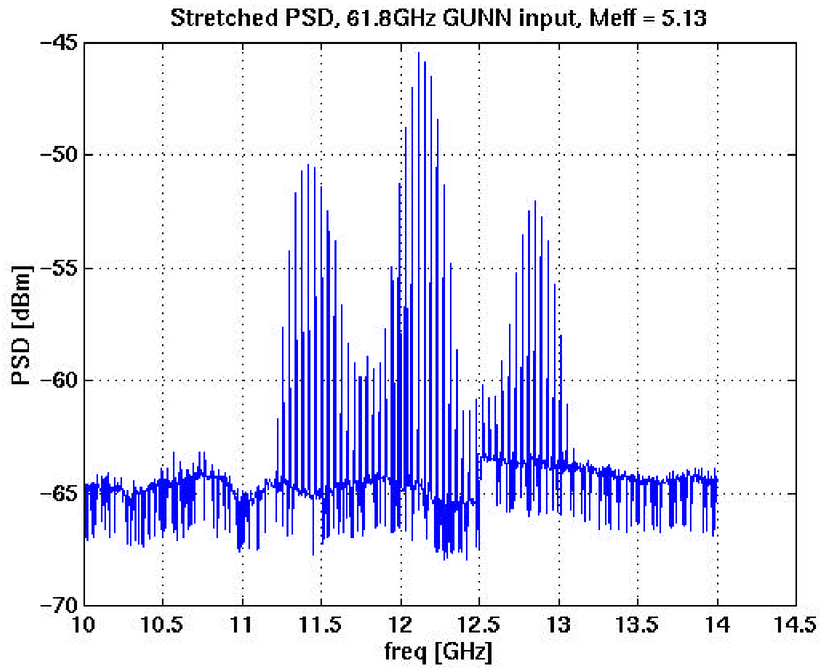




- Sweep oscillator
- L_1=1.5 Km
- L_2=4.5 Km
- Measured Meff 3.86

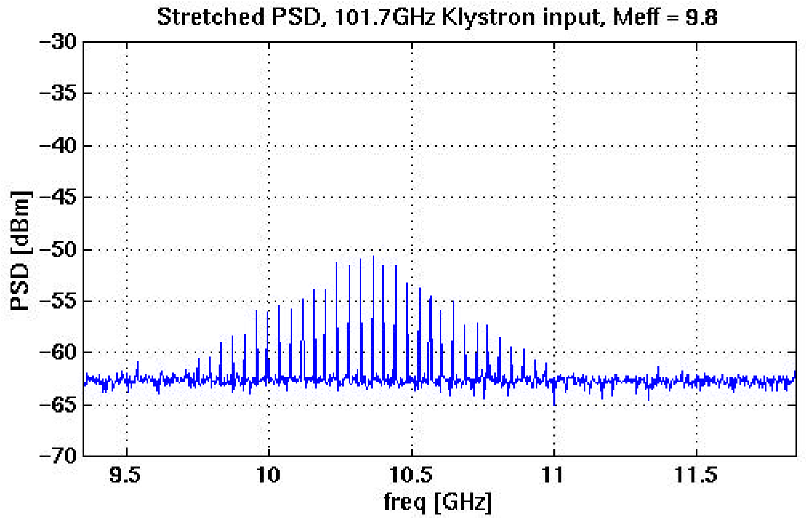
61.8 GHz Time-Stretched Signal

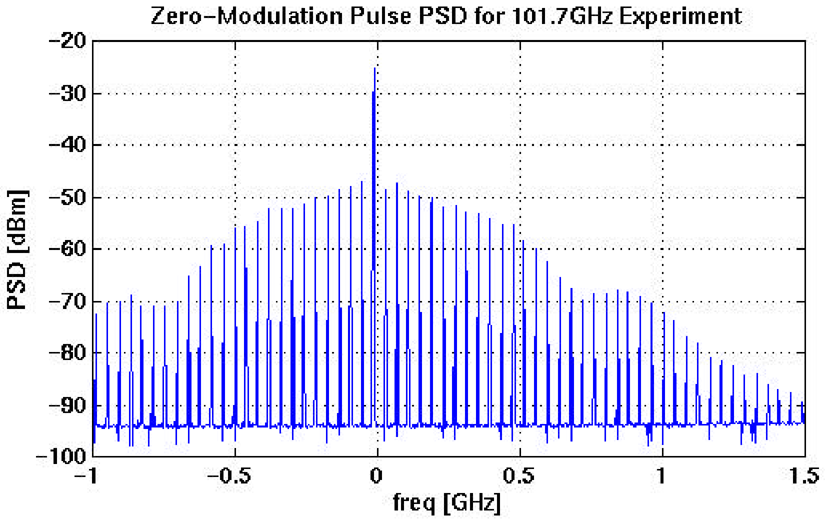
- Source GUNN diode at 61.8 GHz
- L_1=1.5 Km
- L_2=6.5 Km
- Measured Meff 5.13
- PSD shape not significantly changed



101.7 GHz Time-Stretched Signal

- Source Klystron at 101.7 GHz
- L_1=0.5 Km
- L_2=5.0 Km
- Measured Meff 9.8
- Change in input pulse chirp
- Drop in signal level





Stretch Ratios

- Discrepancies between calculated M and measured Meff
- Need to account for dispersive elements ahead of first fiber spool such as 50m fiber patch cord
- Then:

$$\text{Meff} = 1 + \frac{L_2}{L_1 + \delta}$$

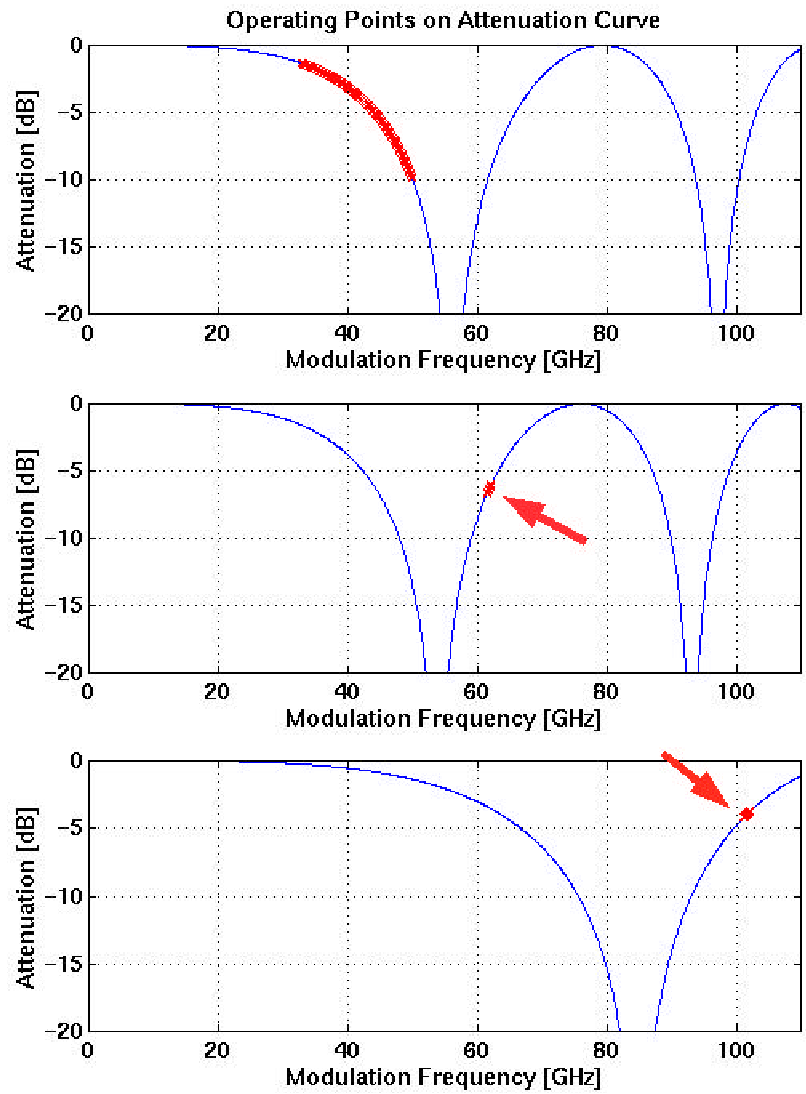
- where δ has length units and represents dispersion equivalent to that length of fiber
- Solutions for δ are correct in magnitude and self-consistent:

f (GHz)	L1 (Km)	L2 (Km)	M	Meff	d (m)
33-50	1.5	4.5	4.00	3.86	73
61.8	1.5	6.5	5.33	5.1	74
101.7	0.5	5	11.00	9.8	68

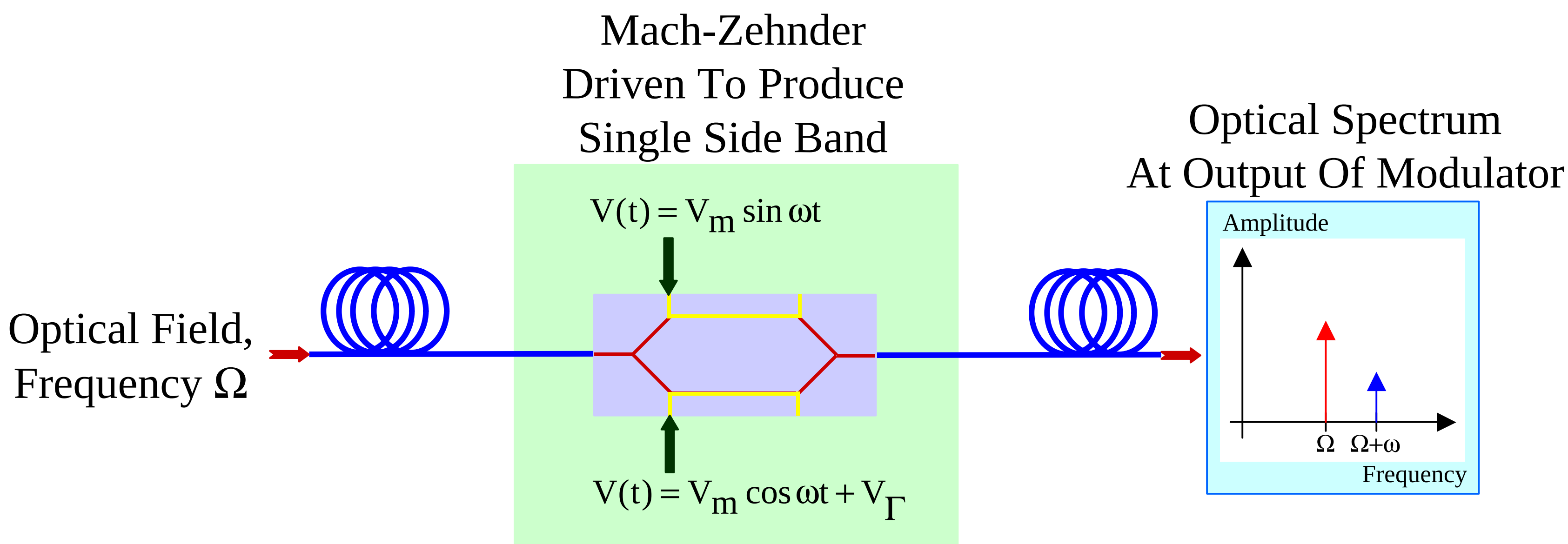
Dispersion Penalty

$$\cos\left(2\pi^2 \frac{\beta'' L_2}{M} f_m^2\right)$$

- Sidebands slip out of phase in L_2 due to group velocity dispersion
- Result: dispersion penalty (Coppinger et. al.)
- Tradeoff: M vs. aperture time vs. bandwidth.
- Practical limit for A/D preprocessing: “must stay in 1st lobe”
- Modulator operation exceeds this limit in our experiment



SSB Modulation



V_Γ chosen to produce additional π/2 optical phase shift

$$I(t) \propto \frac{1}{M} \cdot \exp\left[-2\frac{t^2}{(M\tau)^2}\right] \cdot \frac{J_1(\Delta)}{J_0(\Delta)} \cos\left(\frac{\omega_m}{M} t + \frac{\beta'' L_2}{2M} \omega_m^2 + \frac{\pi}{4}\right)$$

- Amplitude limitation imposed by dispersion penalty removed

Conclusions

- Demonstrated time-stretching of 102 GHz signal
- Enabled by broadband 1.55 μm polymer modulator
- Modulator performance spans useful bandwidth range determined by dispersion penalty
- Importance of optical path length mismatch observed
- Single-Sideband Modulator removes high-frequency attenuation