

# GHz Waveform Generation via Direct Space-to-Time Optical Pulse Shaping and Dispersive Stretching

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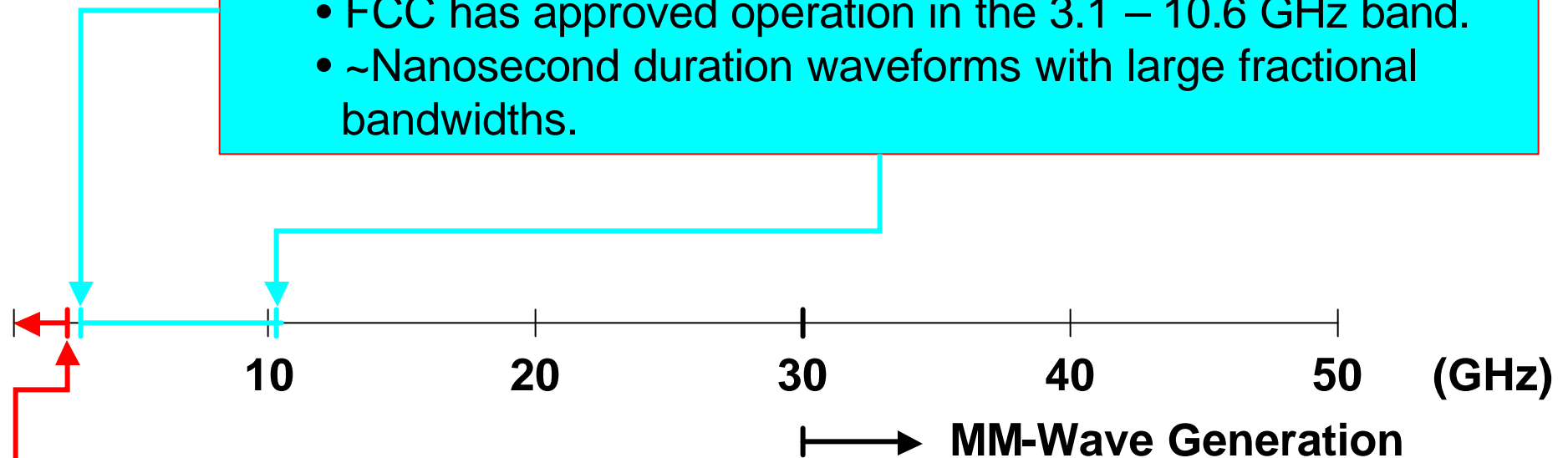
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# Applications of Arbitrary Burst RF Waveforms

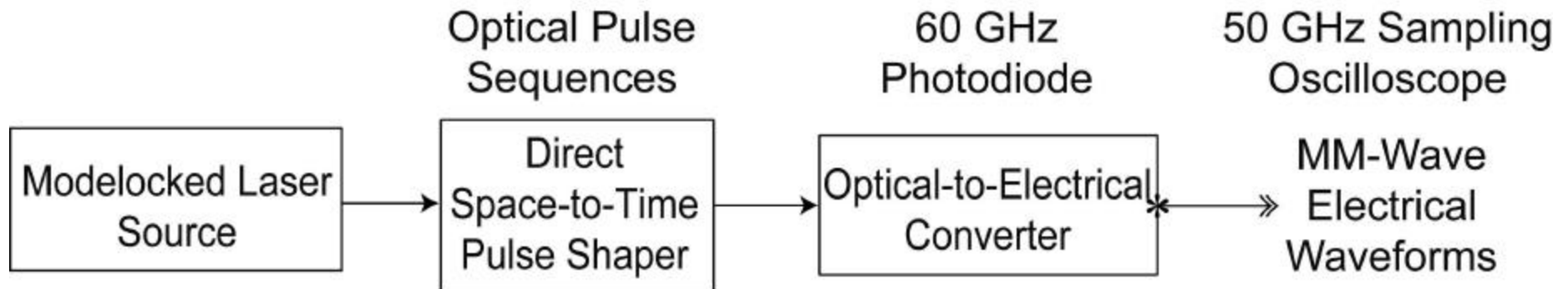
## RF Communications

- Ultra-Wide Bandwidth (UWB) wireless communications
  - FCC has approved operation in the 3.1 – 10.6 GHz band.
  - ~Nanosecond duration waveforms with large fractional bandwidths.



We demonstrate *tunable, cycle-by-cycle* synthesis of arbitrarily shaped electrical waveforms in the GHz range!

# Arbitrary GHz Waveform Generation

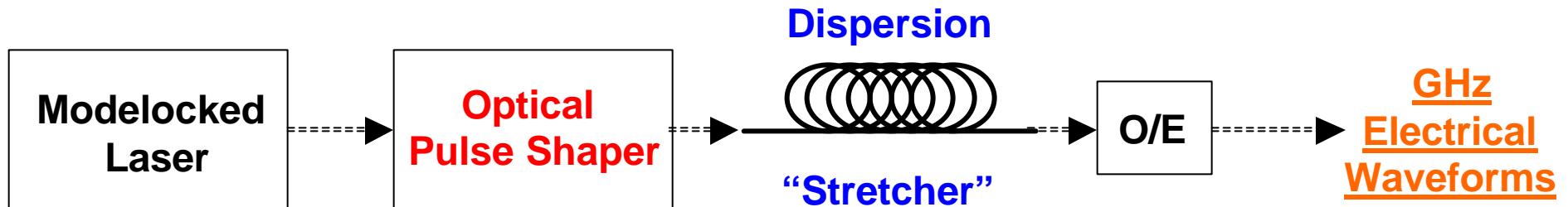


- High rate optical pulse sequences from the DST shaper yield high frequency (30 – 50 GHz) electrical waveforms through fast O/E conversion.



- Duration / center frequency of electrical waveforms determined by duration of optical waveforms prior to O/E conversion.

# Scaling to the GHz Range



- Optical pulse shaper used to generate desired optical waveforms.
- Pulse shapers alone are limited to time apertures in the hundreds of picoseconds...
- Dispersion is used to stretch these optical waveforms prior to O/E conversion  $\mathcal{P}$  allows scaling of waveforms to nanosecond durations.

## • Two methods:

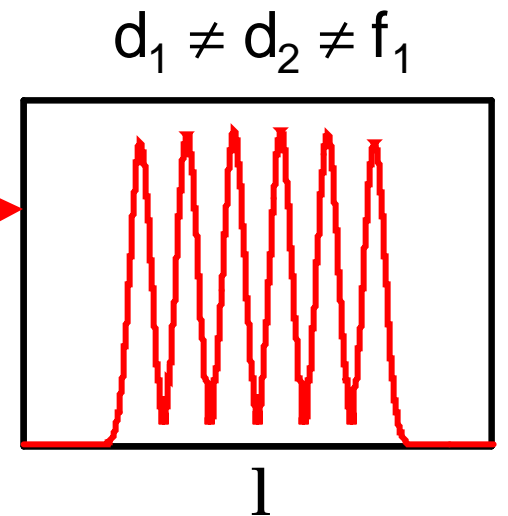
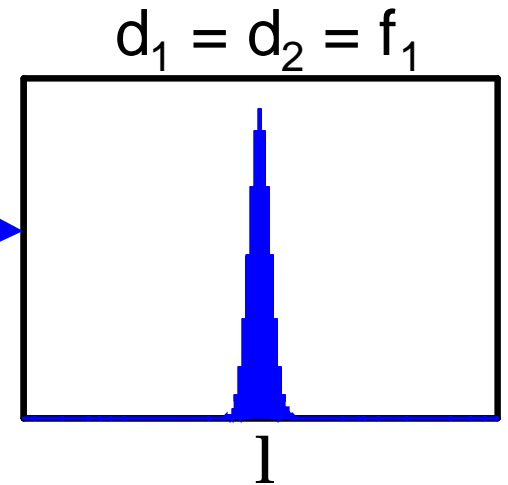
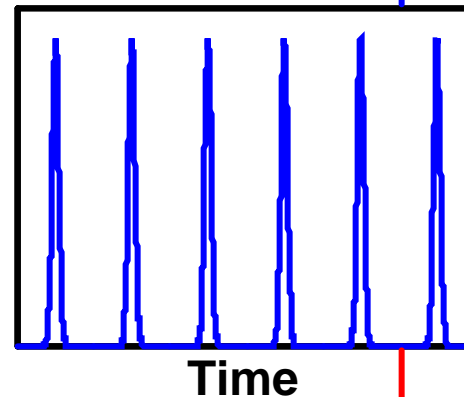
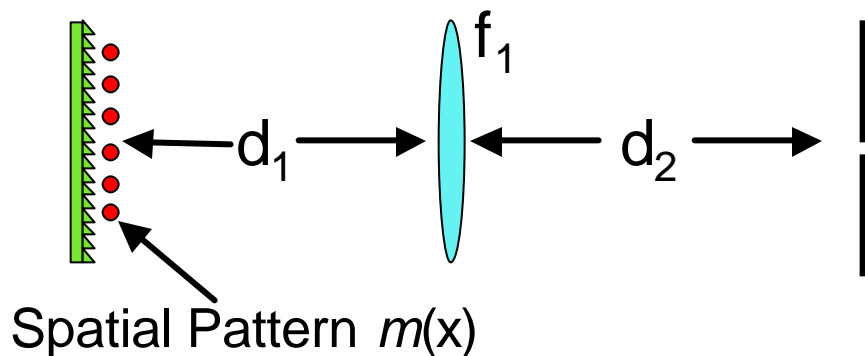
- **Fourier pulse shaping technique**  $\mathcal{P}$  Shape of **optical power spectrum** mapped to time. **Fourier** relation between pulse shaper temporal output and stretched waveform.
  - Chou, Han, and Jalali, IEEE Photon. Technol. Lett., 15, 581, (2003)
  - Toong, Leaird, and Weiner, unpublished
- **DST pulse shaping technique**  $\mathcal{P}$  stretched waveform is a **directly scaled** version of the DST temporal output (as well as the optical power spectrum).

# Frequency Modulation in the DST Pulse Shaper

$$e_{OUT}(t) = e_{IN}(t) * m\left(-\frac{a}{g}t\right) \exp(jAt^2)$$

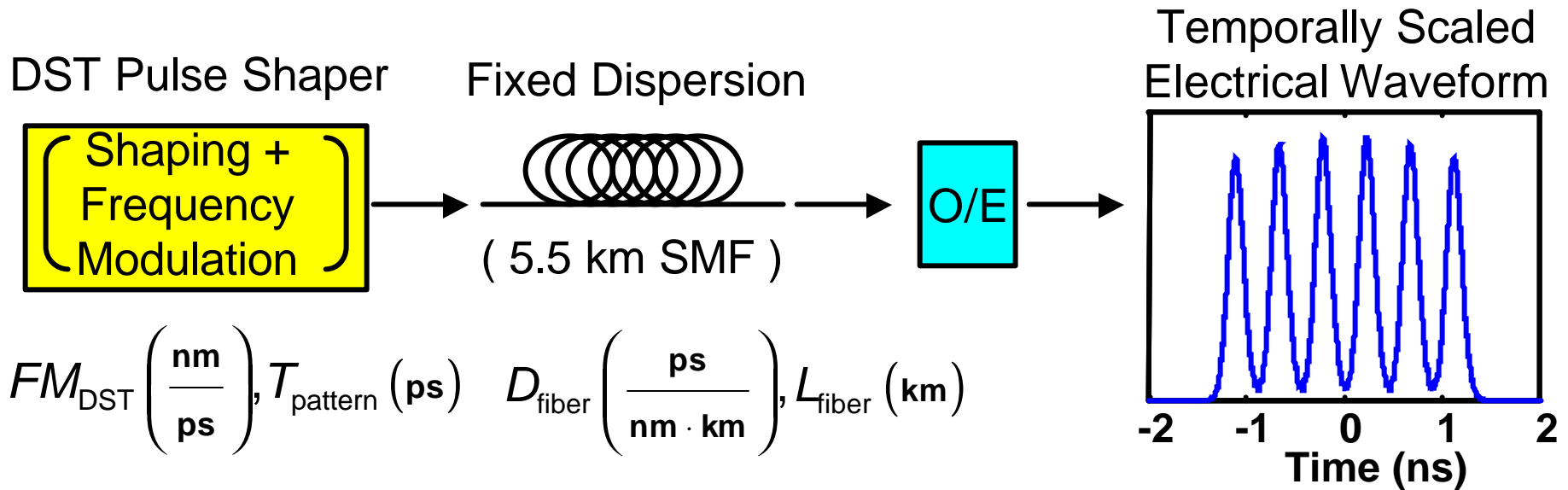
$$A = A(d_1, d_2)$$

- Temporal profile always a scaled version of applied spatial pattern  $m(x)$ .



- Frequency modulation (chirp) can be controlled by varying  $d_1, d_2$ . \*
- Chirp-free for  $d_1 = d_2 = f_1$  \*
- For large frequency modulation, the temporal pattern is mapped onto the optical spectrum.

# Scaling of Electrical Waveforms

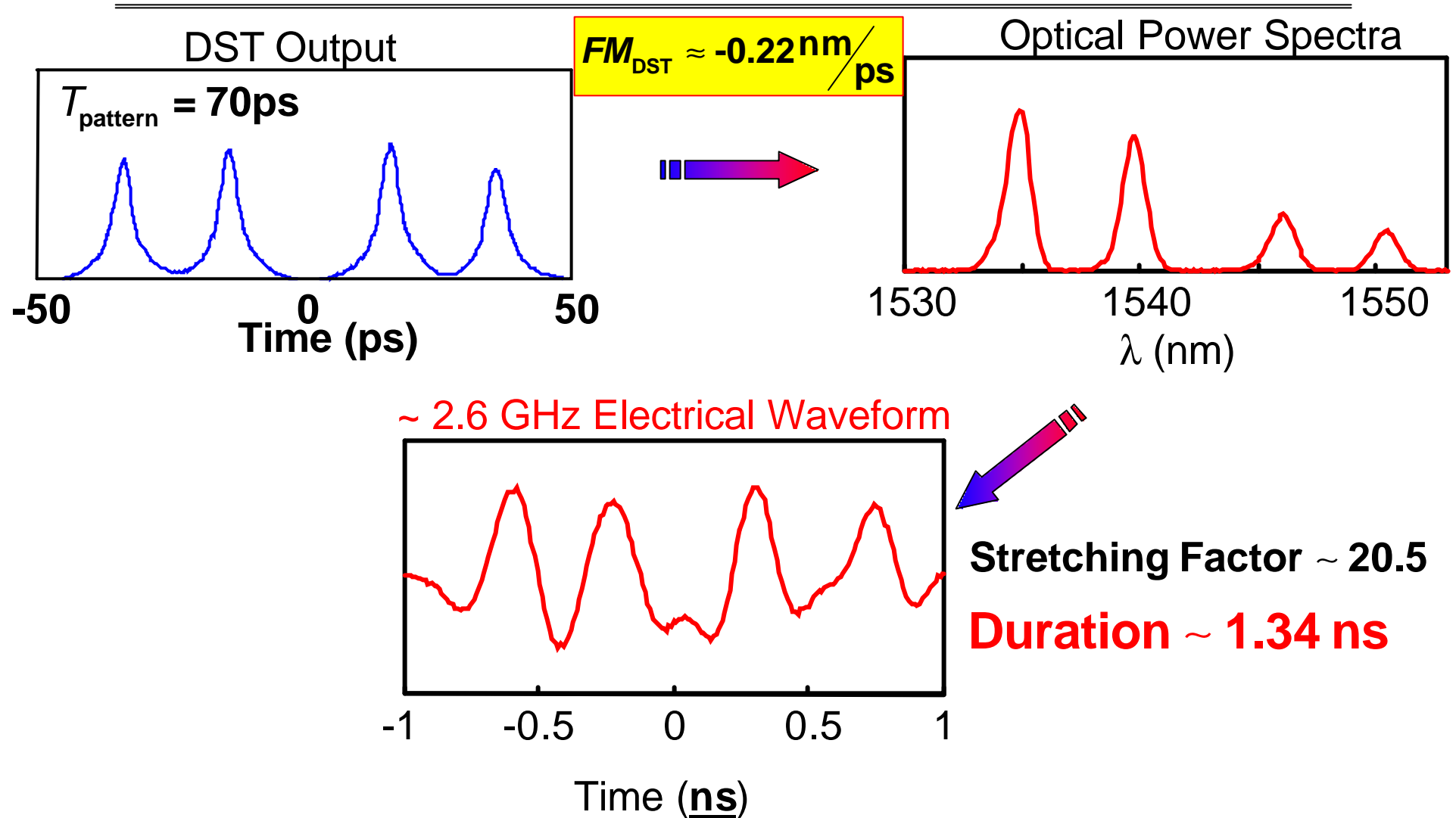


$$\text{Stretching Factor} \sim |FM_{DST}| \cdot D_{\text{fiber}} \cdot L_{\text{fiber}}$$

- For large frequency modulation, spatial pattern mapped onto optical spectrum in the DST shaper.
- Dispersion maps spectral shape onto time domain optical waveform.
- Output waveform is a stretched version of the **DST temporal output!**
- Stretching factor and duration of electrical waveform determined by DST frequency modulation.

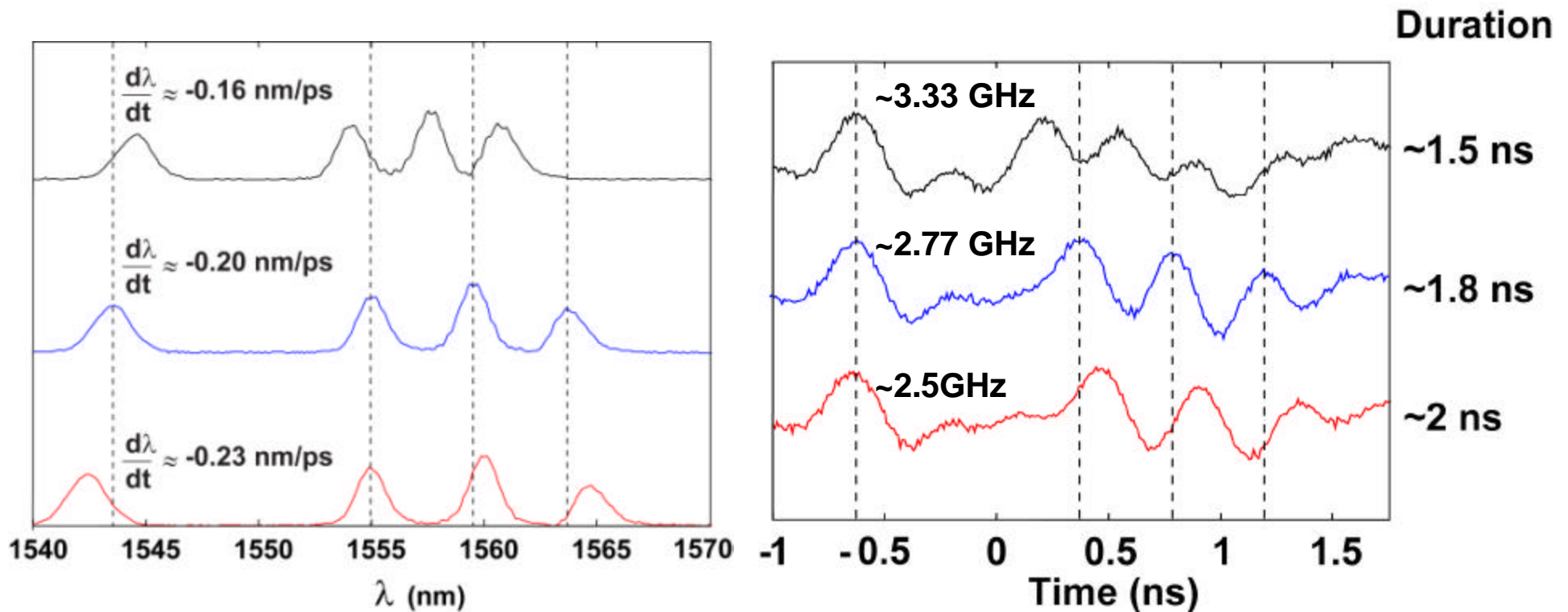
McKinney, Seo, Leaird, and Weiner, submitted to IEEE J. Lightwave Technol. (2003)

# Temporally Stretched Burst Waveforms



- 50 GHz waveforms now scaled to ~2.6 GHz  $\Rightarrow$  20x reduction in frequency!

# Tunable Waveform Scaling



- Small changes in pulse shaping lens position allow tuning of RF waveforms over a range of  $\pm 10\%$ .

McKinney, Seo, Leaird, and Weiner, submitted to IEEE J. Lightwave Technol. (2003)

# Summary

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- The combination of our millimeter-wave generation technique and dispersive stretching enables generation of burst waveforms in the low GHz range.
- The ability to control the temporal quadratic phase in our optical pulse shaper allows waveform duration / frequency to be easily tuned.
- Enabling technology for UWB wireless communications, pulsed radar, and electronic countermeasures.