Fast Widely-Tunable CW Single Frequency 2-micron Laser

Charley P. Hale and Sammy W. Henderson

Beyond Photonics LLC

1650 Coal Creek Avenue, Ste. B

Lafayette, CO 80026

Presented at:

18th Coherent Laser Radar Conference

Boulder, CO

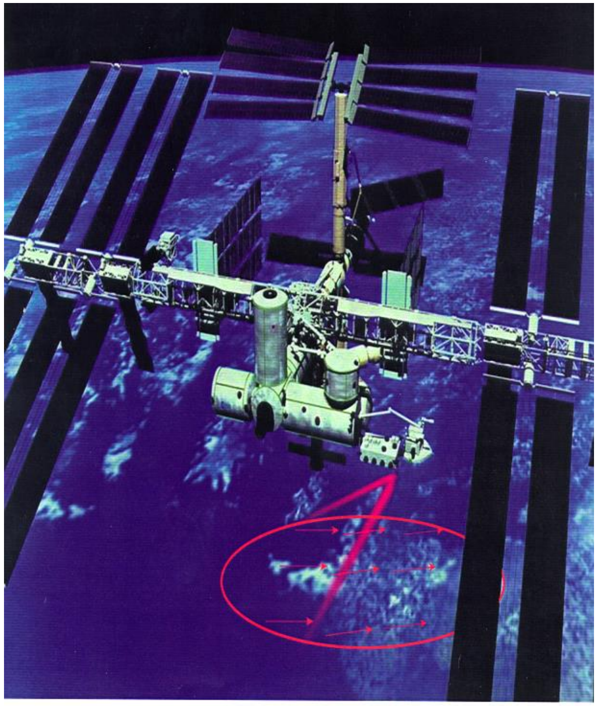
26 June-1 July 2016

Outline

- **Applications of Frequency-Stable and Tunable SLM Lasers**
- **SWIFT: Solid-State Single-Frequency cw Laser Design Overview**
- **Wavelength/Frequency Tuning of SWIFT**
- **Frequency Stability of SWIFT Prototype**
- **Summary**

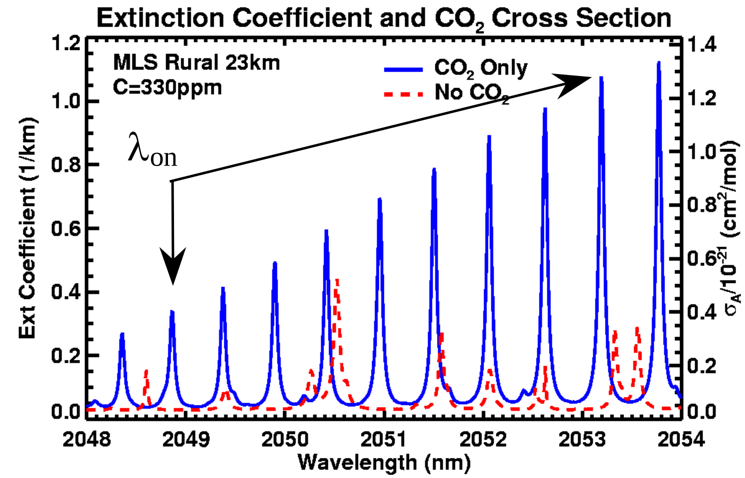
Applications: Global Wind Monitoring

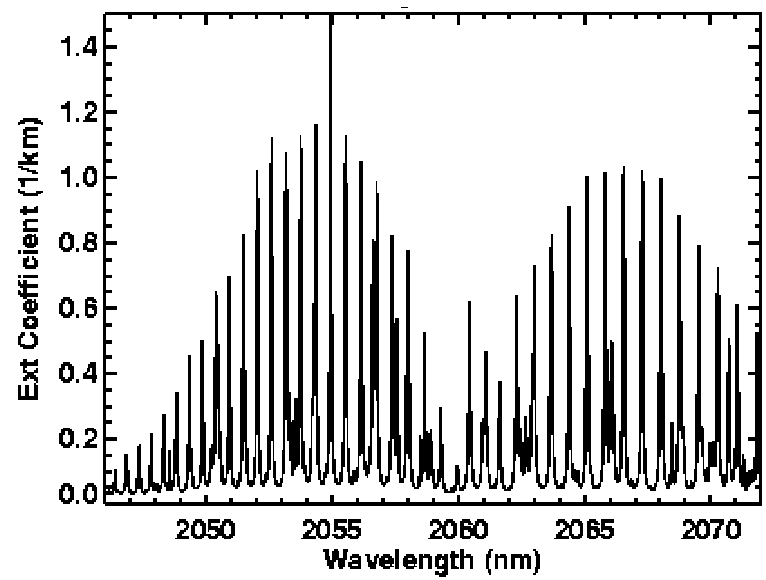
- **Application**
  - Eyesafe Doppler lidar continues to be of great interest for global characterization of the winds from space
- **Problem**
  - System efficiency is critical
  - Doppler shifts from space platforms exceed COTS high efficiency 2 um detector bandwidths
    - Typical high QE extended wavelength InGaAs BW = 500 MHz
    - Typical platform velocities demand +/- 7 GHz
- **Solutions**
  - Improved detector/receiver bandwidth
    - High risk detector development
    - Expensive RF electronics with higher noise figure
  - Offset locked frequency MO/LO lasers
    - Complex optical servo
    - Fast slew rate and settling time



Applications: Differential Absorption Lidar (DIAL)

- **Application**
  - **CO2 concentration monitoring**
    - **Global warming**
- **Problem**
  - **Need frequency agile Laser**
    - **to probe "on" and "off" absorption wavelengths**
  - **Or to tune through absorption features**
- **Solution**
  - **Offset-locked frequency agile cw local oscillator laser**

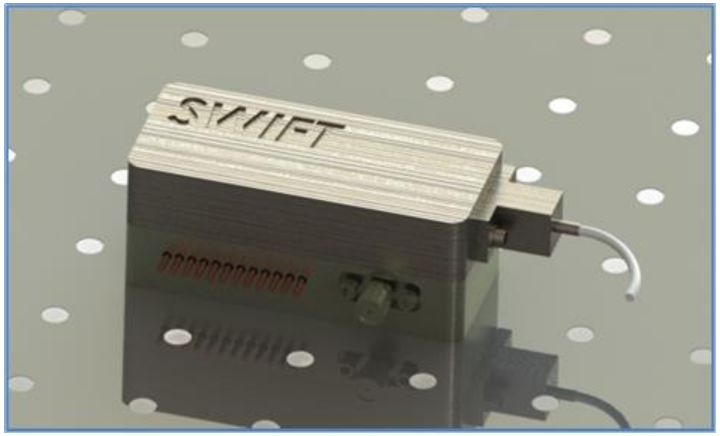


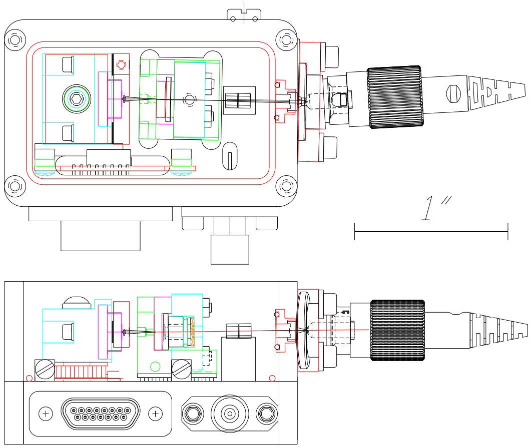


SWIFT cw SLM Laser

BEYOND Photonics

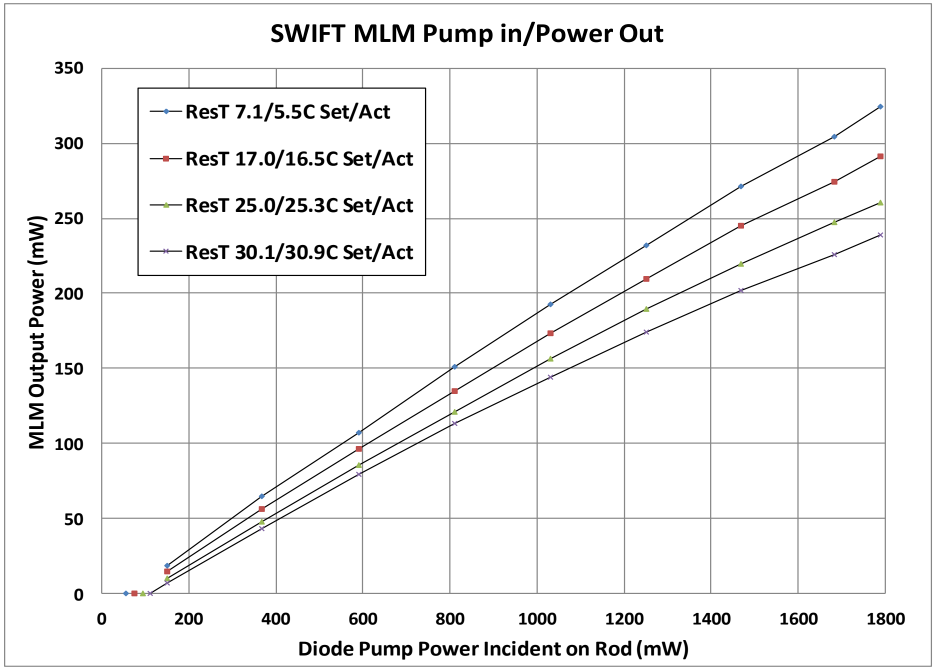
- ✓ Tm,Ho:YLF: 2047-2059 nm factory-set peak wavelength; user-tunable ± 0.14 nm. Other NIR and SWIR wavelengths possible
- ✓ Integral 60 dB Faraday isolation and PM fiber coupling
- ✓ CW single-frequency output power in excess of 30 mW; higher powers possible.
- ✓ Very compact laser head: 1.2” W x 2.8” L x 1” H; conduction cooled; smaller version under development
- ✓ Fast piezo frequency tuning (>20 GHz); also capable of thermal tuning
- ✓ Linewidth less than 10 kHz/ms (dependent on piezo drive characteristics)
- ✓ Long-term frequency drift less than 1 GHz/day. Improved linewidth and long-term frequency stability possible by locking to an external reference.

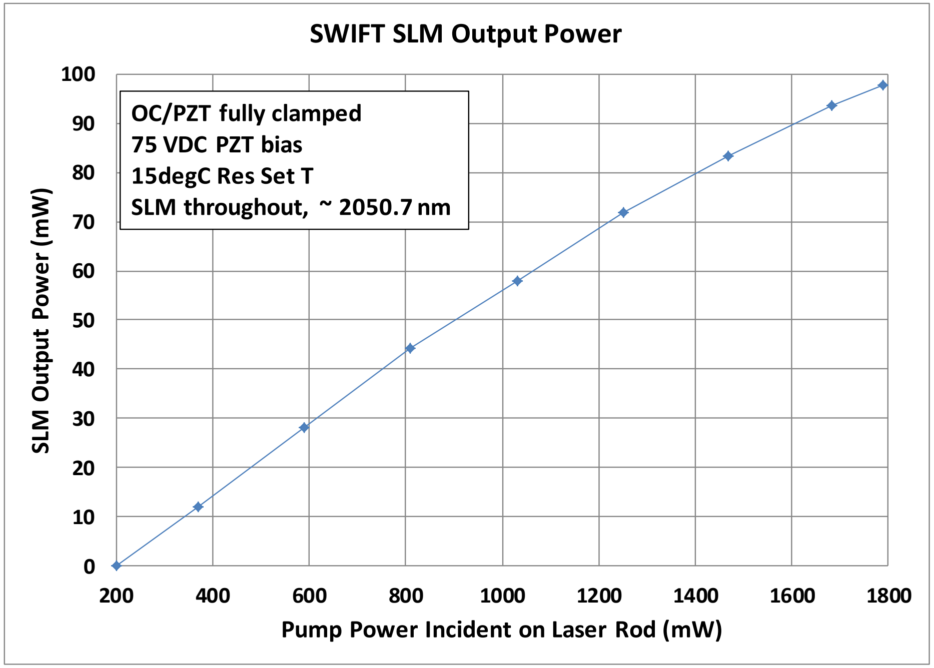




SWIFT cw Diode-Pumped Output Power

- **SWIFT prototype uses 6% Tm, 0.5% Ho-doped YLF, 1 mm length, pumped at 780 nm with < 2 W; SLM operation via thin intracavity etalon**
- **Very short crystal length limits pump absorption but permits extremely short cavity length/wide FSR (61 GHz in prototype); longer crystals for applications requiring less tuning range will be more efficient**

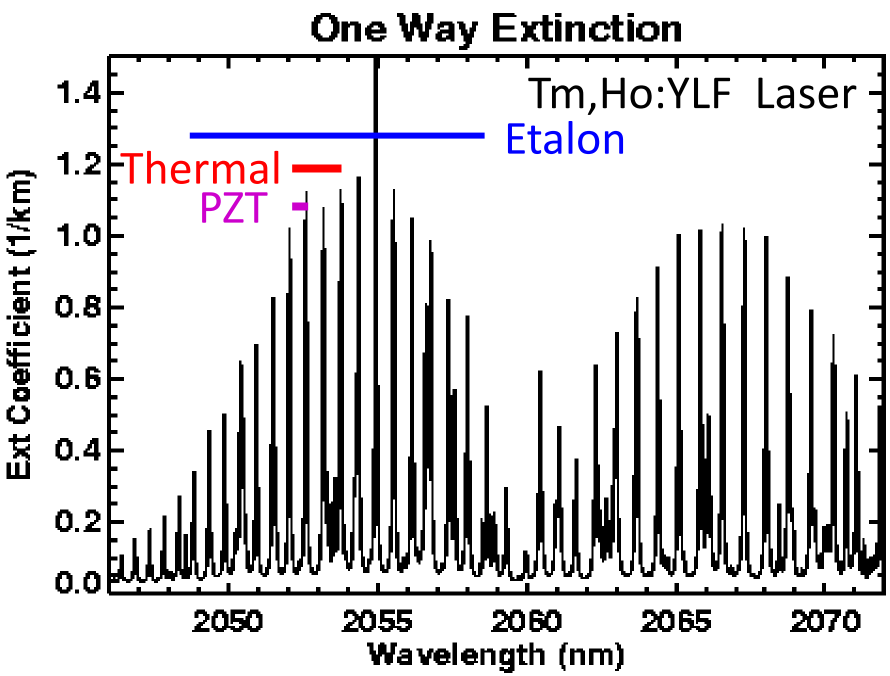


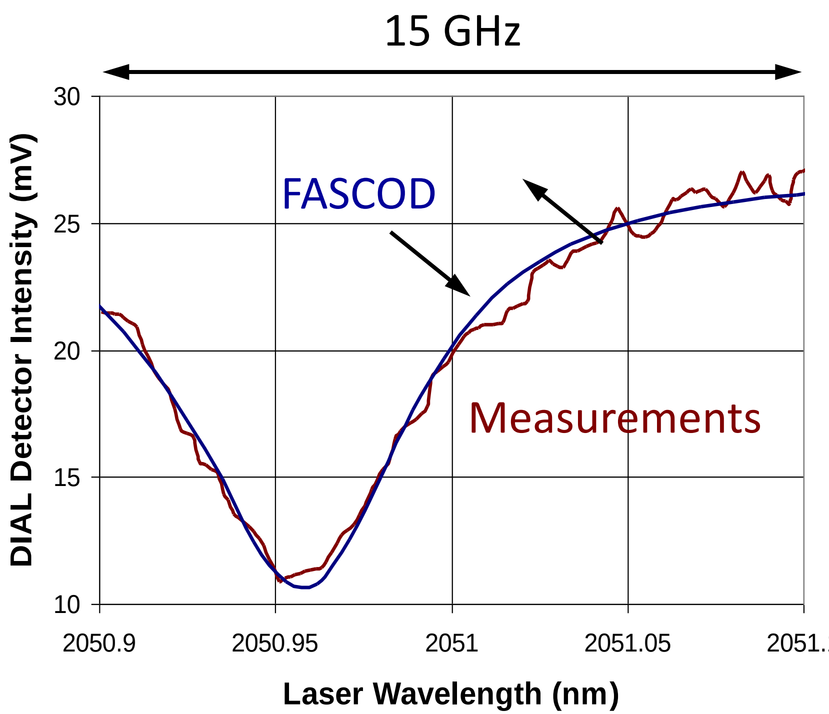


PZT Tuning Example
Tm:Ho:YLF for CO_2 Absorption Measurements

BEYOND Photonics

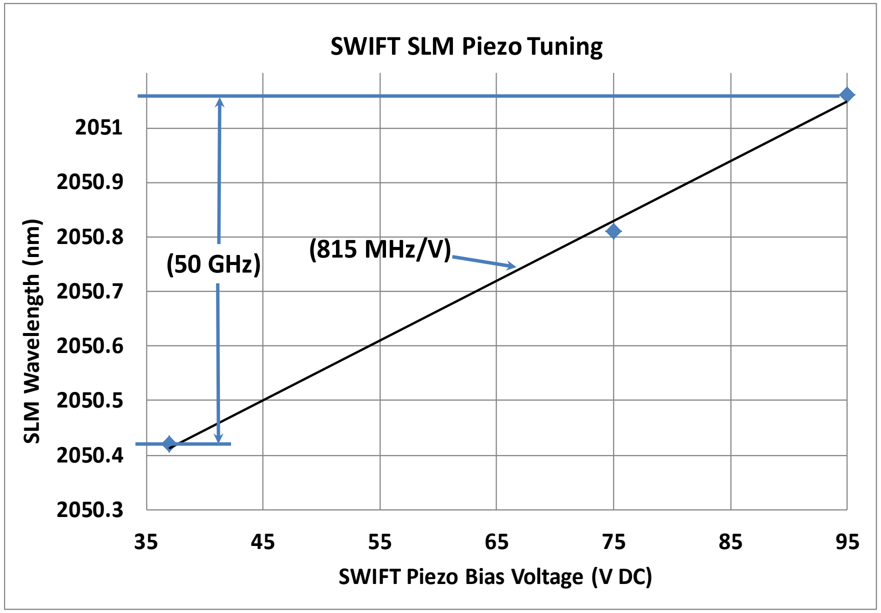
- **CO2 Absorption feature measured with PZT tuned Tm,Ho:YLF**
  - **Intracavity etalon coarse tuning to 2051 nm (2047-2059 nm possible)**
  - **Thermal tuning to select e.g. 2050.95 absorption feature**
  - **PZT tuning over absorption feature**
    - **Direct detection measurements agree with FASCOD/HITRAN (320 ppm CO_2)**

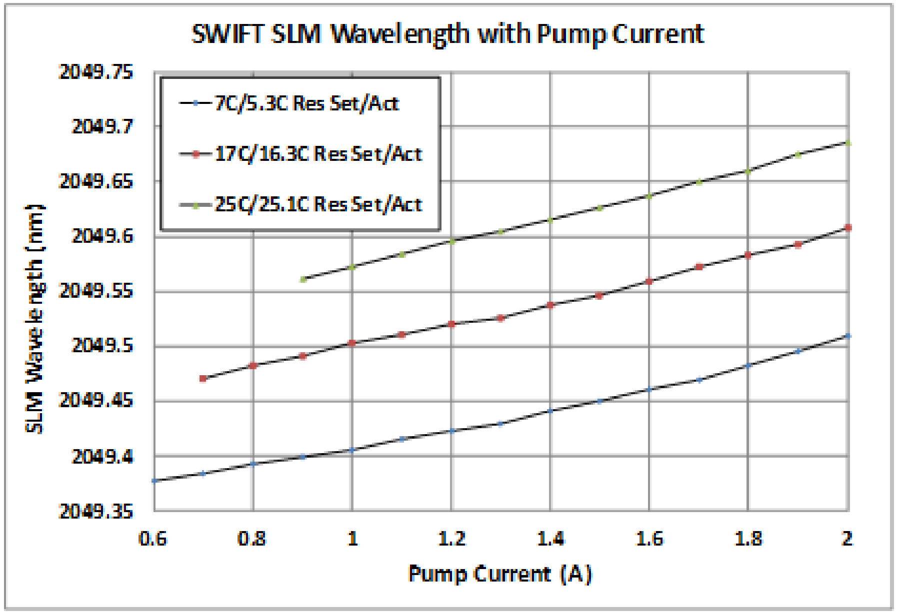




SWIFT Piezo Tunability

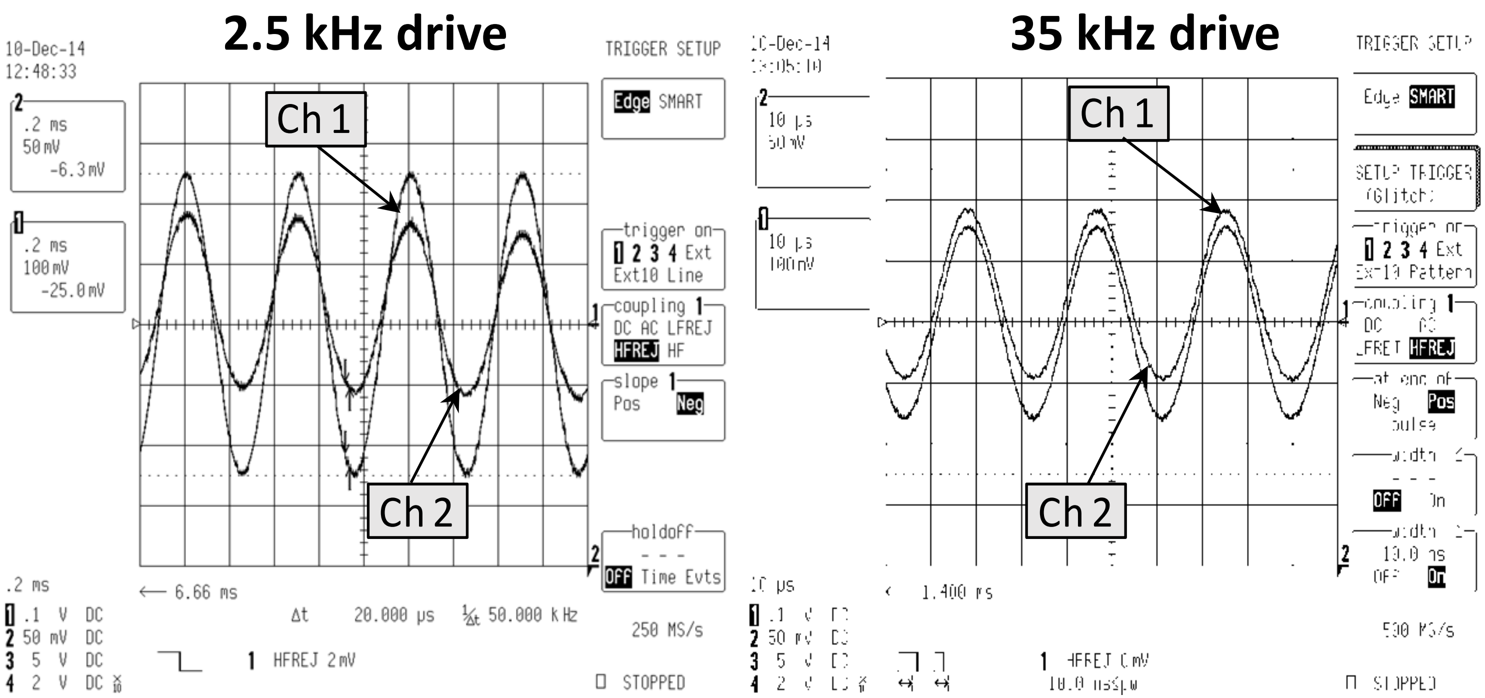
- SWIFT prototype cavity FSR is 61 GHz via very short crystal and reentrant output coupler design
- Very small, low-V PZT actuator scans cavity length across FSR resulting in as much as 50 GHz (0.7 nm) SLM mode-hop-free tuning range
- Piezo V: ~ 815 MHz/V; Resonator T: ~480 MHz/ºC; Pump I: ~ 7.5 MHz/mA





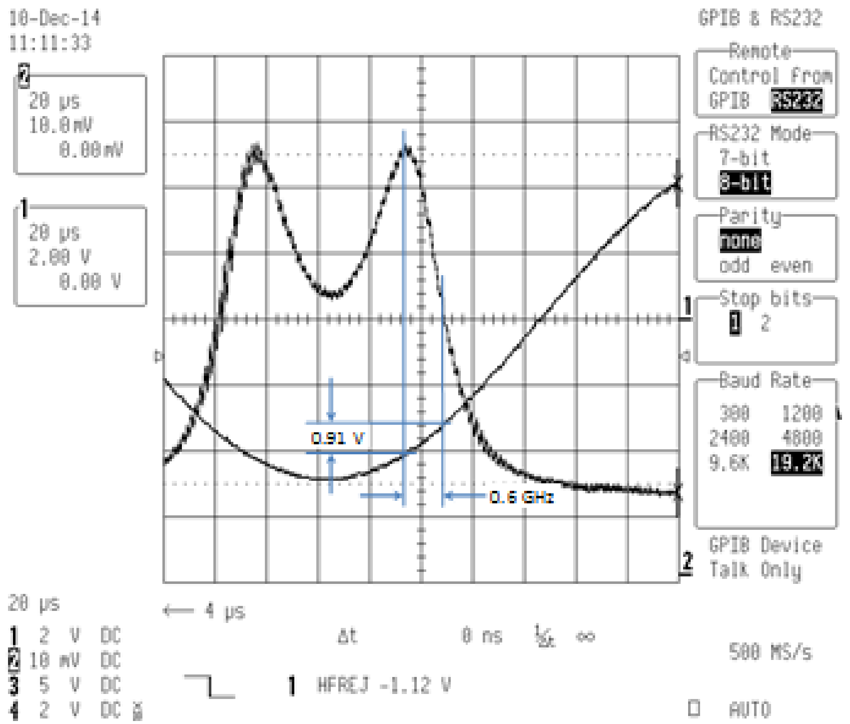
SWIFT Piezo Tuning Bandwidth

- **Ring PZT is mechanically loaded by output coupler and exhibits ~ 40 kHz bandwidth, -20/+100 V; tuning ~ 800 MHz/V**
- **Small-signal (0.5 V p-p; 400 MHz p-p) 1st resonance ~ 38 kHz**
- **Sinusoidal PZT drive (Ch 1) produces laser frequency modulation (Ch 2); still well-behaved (minimal phase shift) at 35 kHz drive frequency**



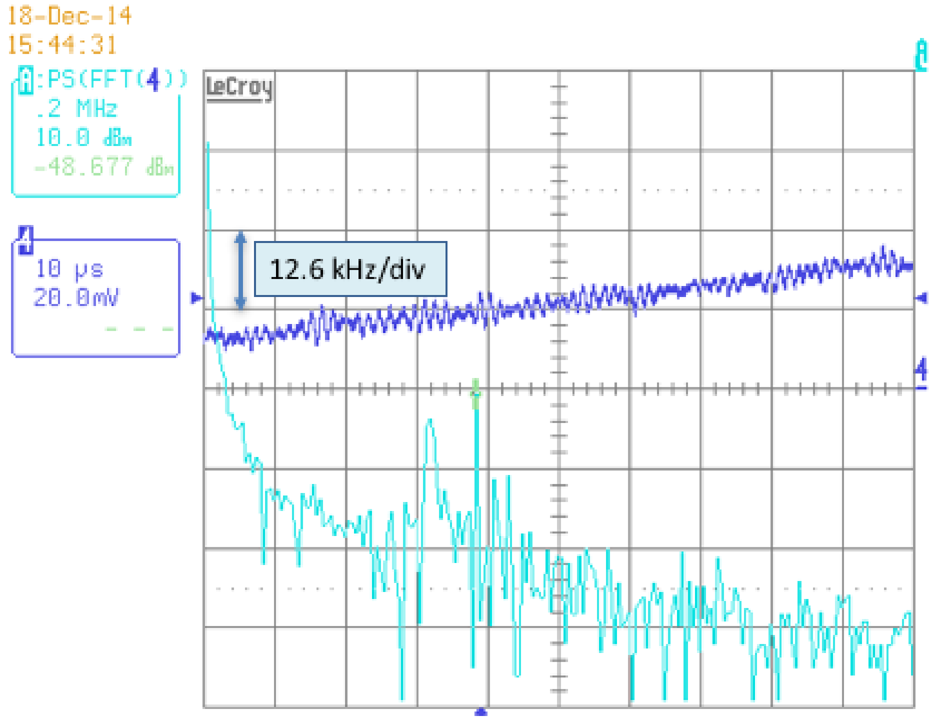
SWIFT Piezo Tuning Bandwidth

- **Large signal (10 V p-p) @ 3 kHz produces ~ 8 GHz Δν in 170 μs**
- **No phase delay up to ~ 10 kHz sinusoidal drive frequency; didn't exceed due to PZT damage concerns**
- **Static 80 GHz Fabry-Perot interferometer used to assess broad laser slew rate; e.g., 0.9 V ΔV results in ~ 0.7 GHz/V sensitivity**



SWIFT Prototype Frequency Stability

- SWIFT prototype head was not sealed and so was open to air currents, barometric pressure change, acoustic noise in lab
- Nominally linear slope of a static 1 GHz FSR F-P interferometer fringe was cross-calibrated: 0.63 kHz/mV photodiode output; 100 μs captures
- Typical prototype stability ~ 60 kHz p-p out of 10^{14} Hz; expect ~ 5 kHz/ms with fully sealed laser head



Summary

- Improvements continue in cw SLM MO/LO lasers for coherent winds, atmospheric DIAL; potential for next-gen gravitational wave det
- SWIFT laser developed under NASA Phase I SBIR funding extends performance at 2.05 μm; potential for extension to other wavelengths of interest (1, 1.5, 1.6, 2.0 μm)
- Basic design readily applicable to higher cw powers, Q-switched pulsed applications
- Product versions at 2.05 μm expected 2016/17