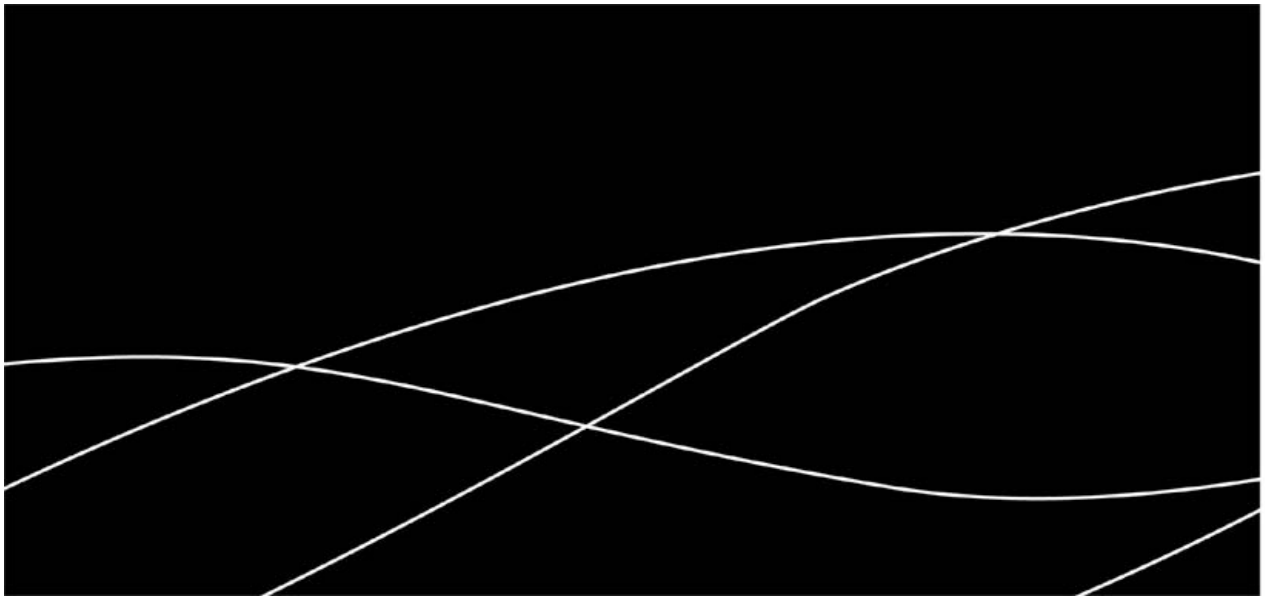
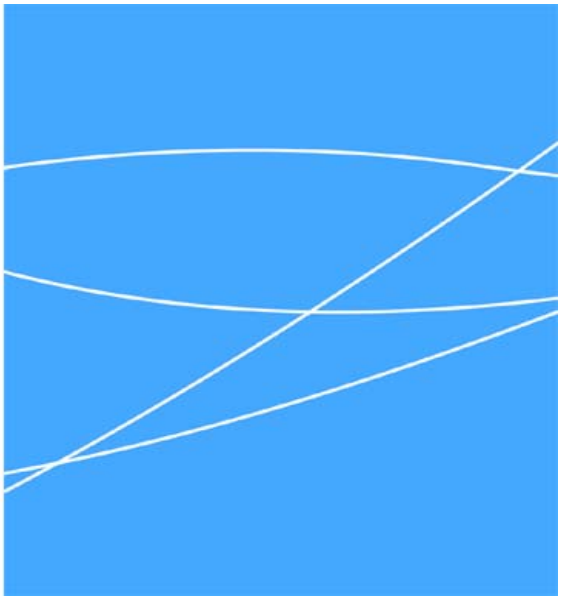




Symmetricom Capabilities for IMPACT Collaboration (using CSAC by way of example)

IMPACT Industry Day
Arlington, VA May 15, 2008

Michael Garvey
rmgarvey@symmetricom.com

The views, opinions, and/or findings contained in this presentation are those of the presenter and should not be interpreted as representing the official views, either expressed or implied, of the Defense Advanced Research Projects Agency or the Department of Defense.

DRAPER LABORATORY

Symmetricom®

Sandia National Laboratories

Approved for Public Release, Distribution Unlimited

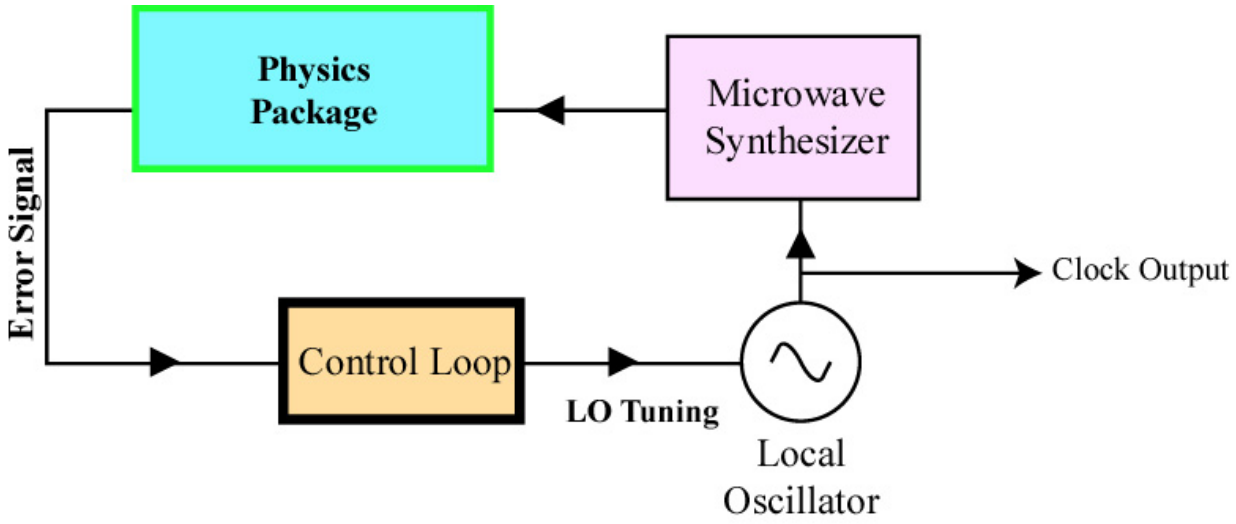
Team Roles

- Symmetricom
  - Architecture for atomic interrogation
  - Optics
  - Electronics
  - Firmware and algorithms
  - Characterization of CSAC performance
- Charles Stark Draper Laboratory
  - Physics package design, fabrication and testing
- Sandia National Laboratories
  - Laser design, fabrication and testing
  - Design of microwave interface to laser

Phase Overview

- Phase I: identify architecture and downselect approaches
  - Cesium interrogation (vs rubidium)
  - Coherent Population Trapping interrogation (vs microwave interrogation)
  - D1 optical resonance; design and fabricate 894 nm lasers
  - Polyimide suspension in vacuum for low power physics package
  - Meet the DARPA milestones
- Phase II: design, build and test as proof of concept
  - Develop components and processes
  - Start long term tests (suspension, vacuum/getter)
  - Build & test prototypes
- Phase III: refine and optimize design
  - Optimize atom interrogation
  - Refine components and processes
  - Add high resolution frequency synthesis
  - Develop autonomous start-up and add supporting servos
  - Implement temperature compensation to improve thermal stability
  - Exploratory environmental testing

CSAC (and most other atomic clocks)



Atomic resonance is intrinsically more stable than quartz local oscillator

"Natural" atomic microwave resonance frequency is synthesized from RF LO

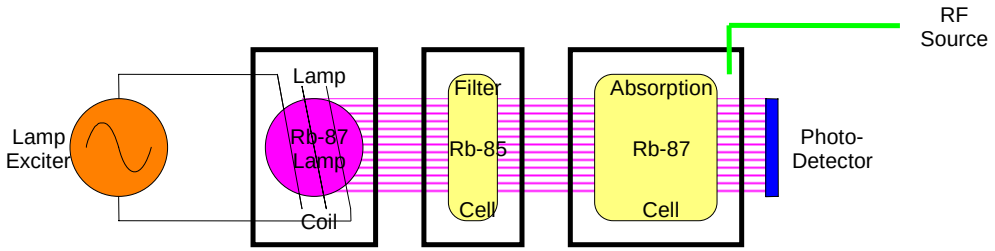
Control Loop continuously steers LO frequency to atomic resonance

RF output *(10 MHz)* embodies stability of atomic resonance

Low-power Physics Strategy

Conventional Rb Physics

- Requires resonant microwave cavity
- RF Discharge lamp *(1 Watt)*
- 3 (2?) cells, ovens, controllers

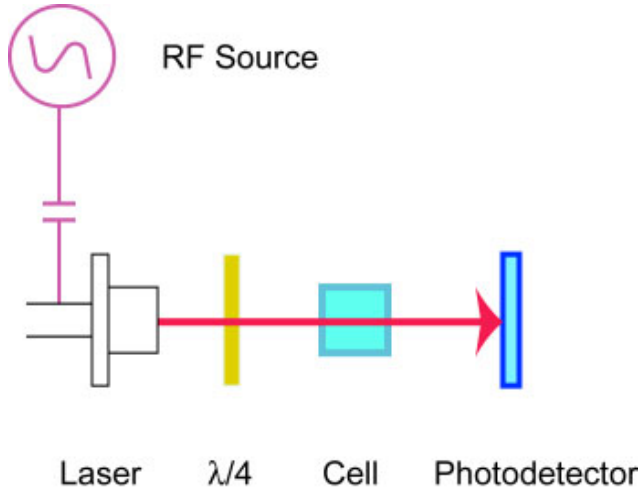


RF Discharge Lamp

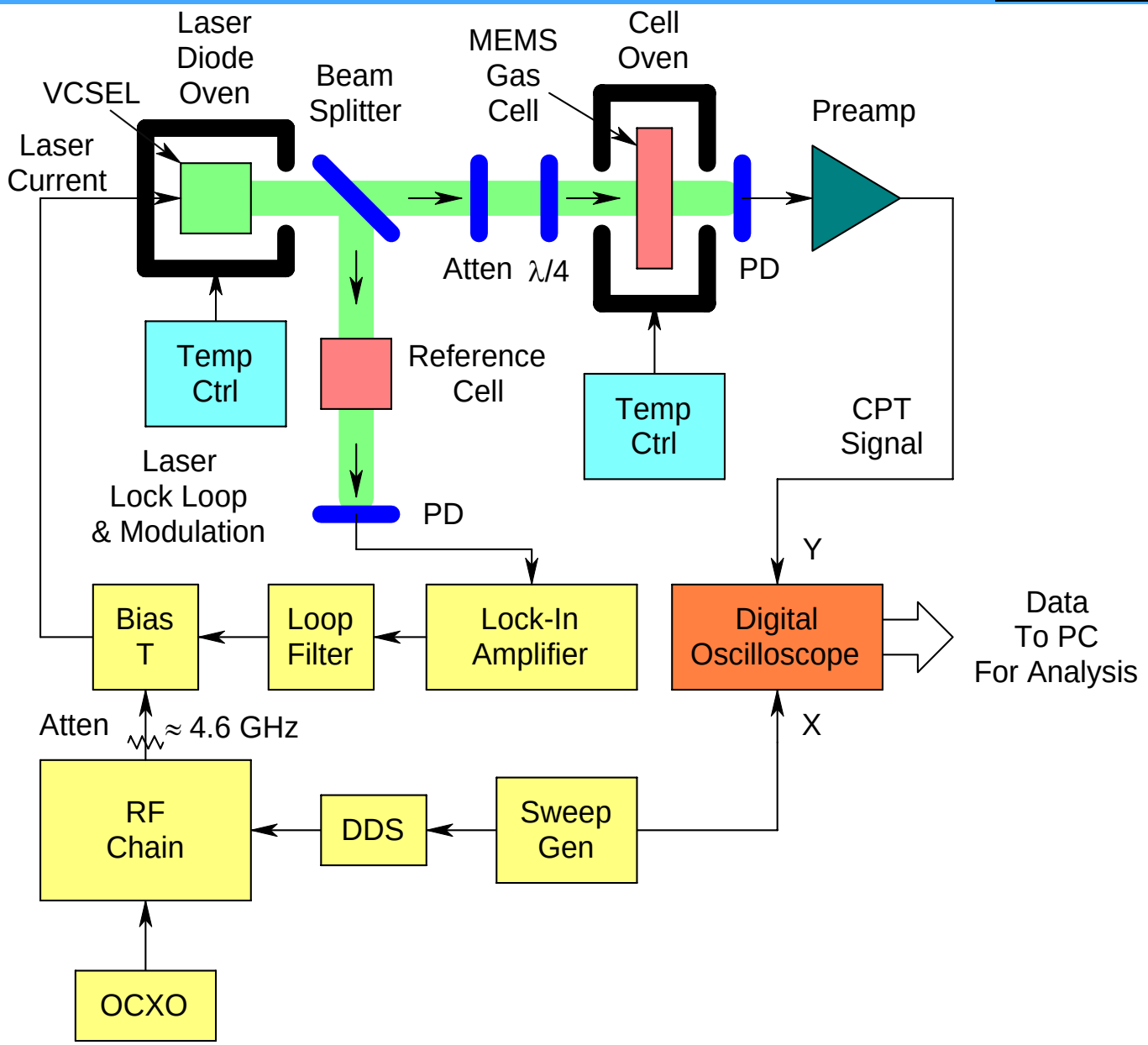
Resonance Cell In Microwave Cavity

Coherent Population Trapping (CPT) Physics

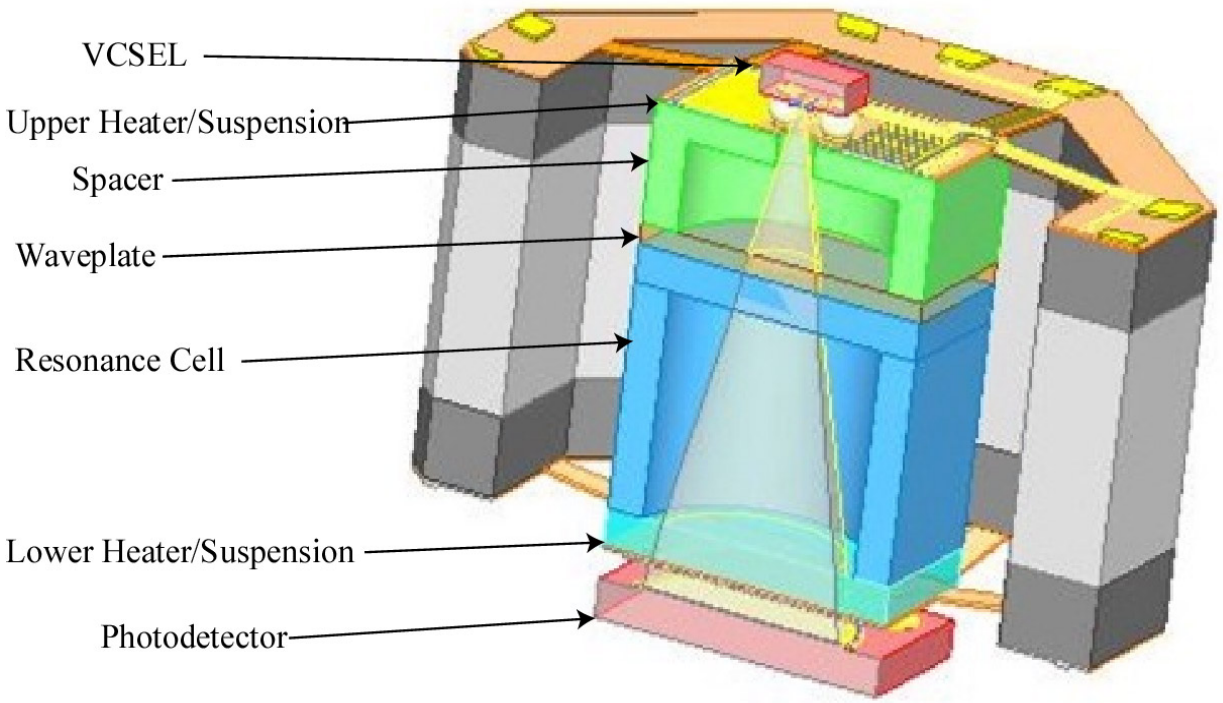
- High-bandwidth Vertical-Cavity Surface Emitting Laser *(VCSEL)*
- Microwaves applied directly to VCSEL *(No cavity)*
- Potential for very small oven assembly



Phase I Resonance Linewidth Lab Test-bed

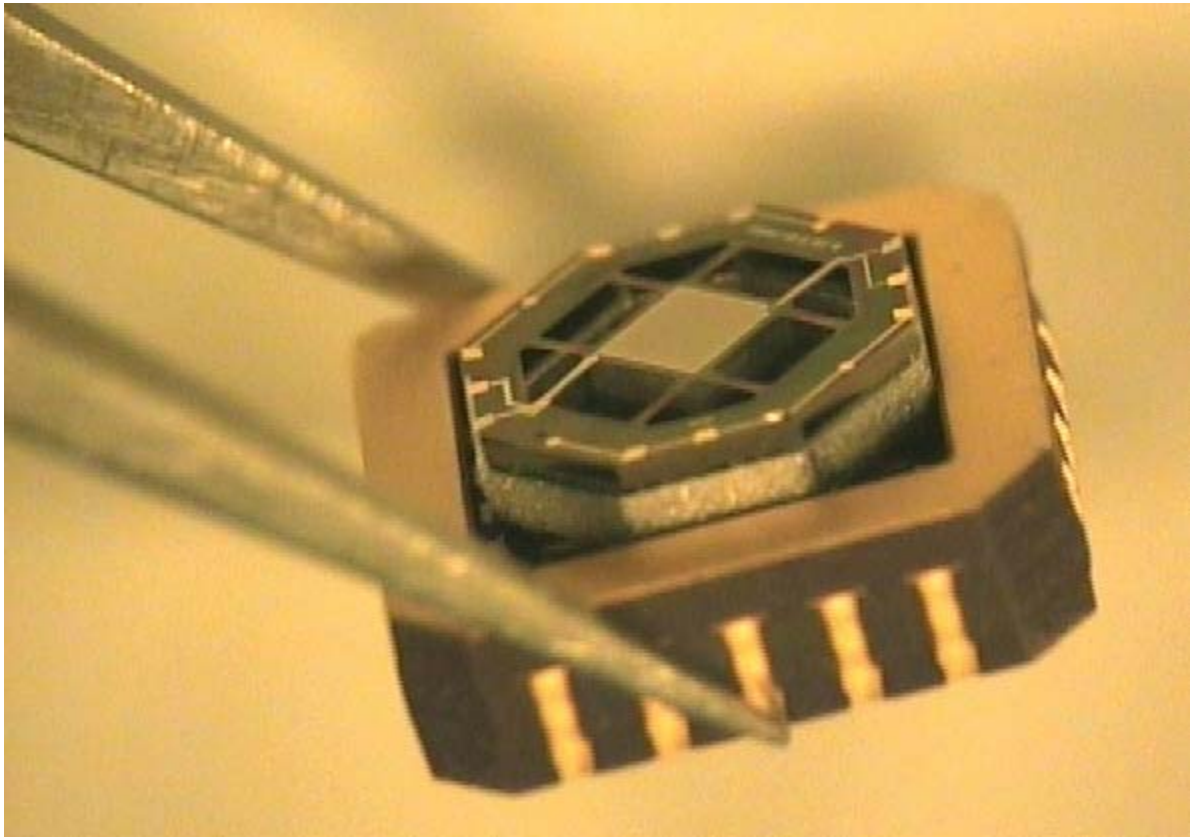


The 10 mW Physics Package



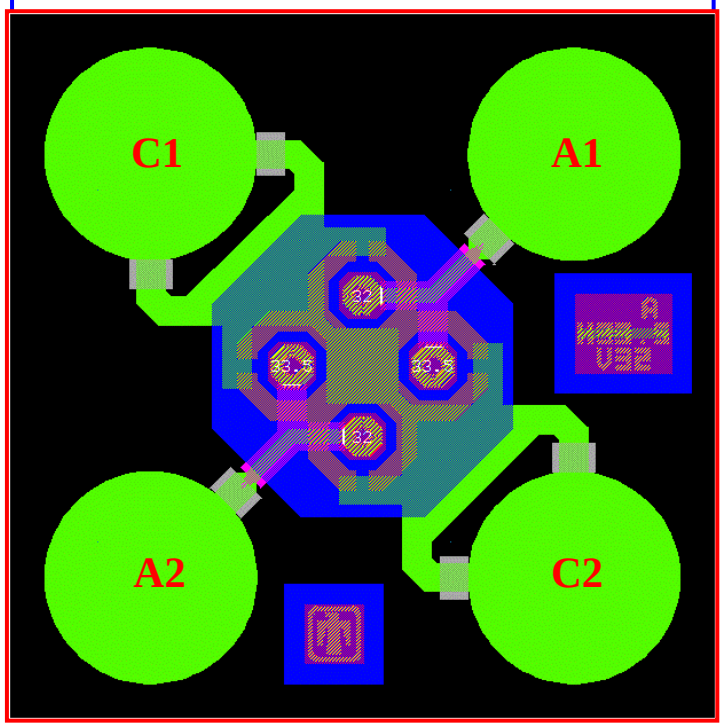
- Tensioned polyimide suspension
- Microfabricated Silicon vapor cell
- Low-power Vertical-Cavity Surface Emitting Laser (VCSEL)
- Vacuum-packaged to eliminate convection/conduction
- Overall Thermal Resistance 7000°C/W

Physics Package

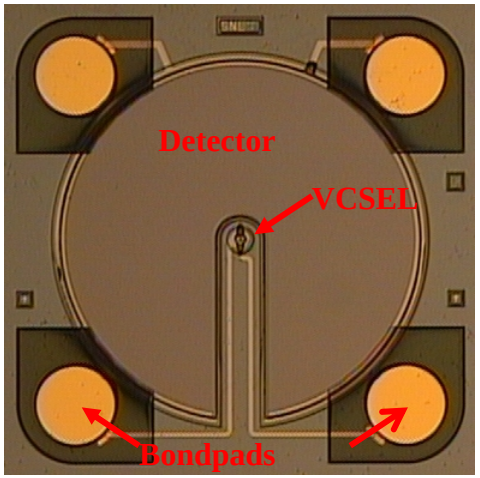


PP-III VCSEL

0.5-mm VCSEL Chip Layout

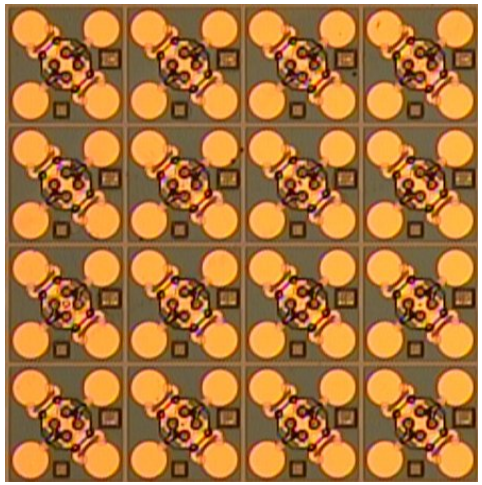


Old: VCSEL/Detector

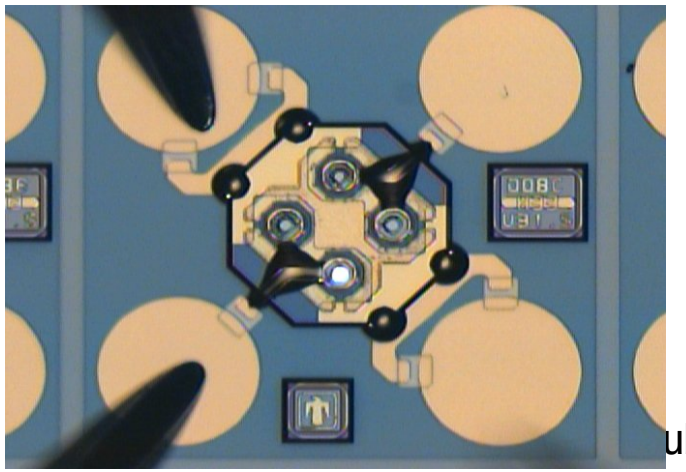


2mm

New: 16 VCSEL pairs



2mm

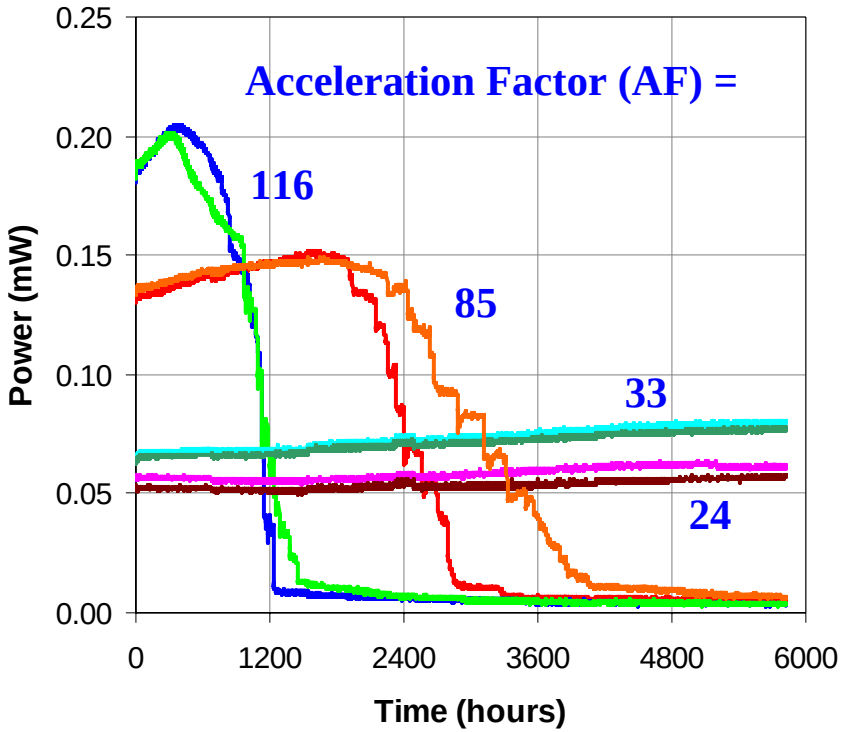


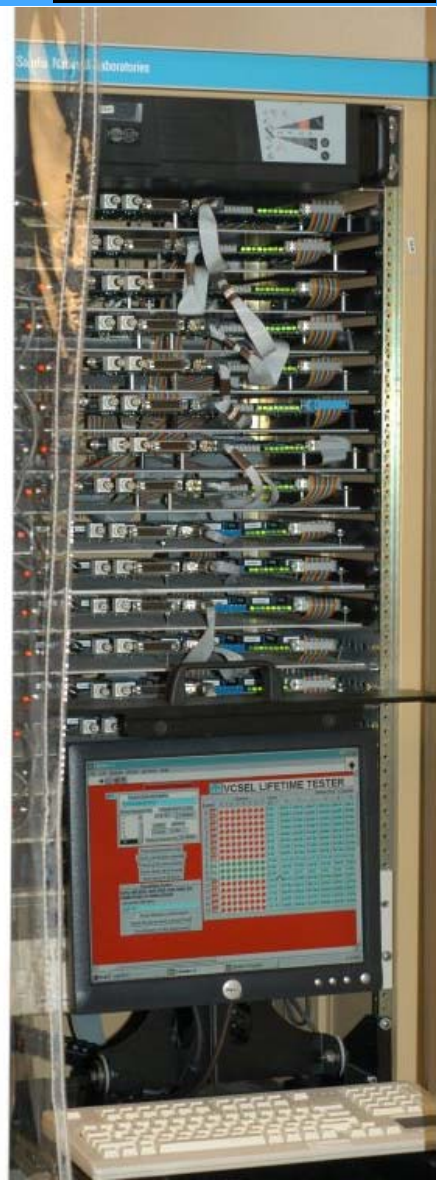
16x reduction in VCSEL chip area

- 16X Cost Reduction
- Redundant VCSELs (2/chip)

VCSEL Reliability

- ESD causes majority of failures
- Remaining failures due to defects
- Accelerated life test underway at Sandia
  - 5 x 8 devices under test
  - 10 months of data available
  - Latest results predict >10 years MTTF under CSAC operating conditions

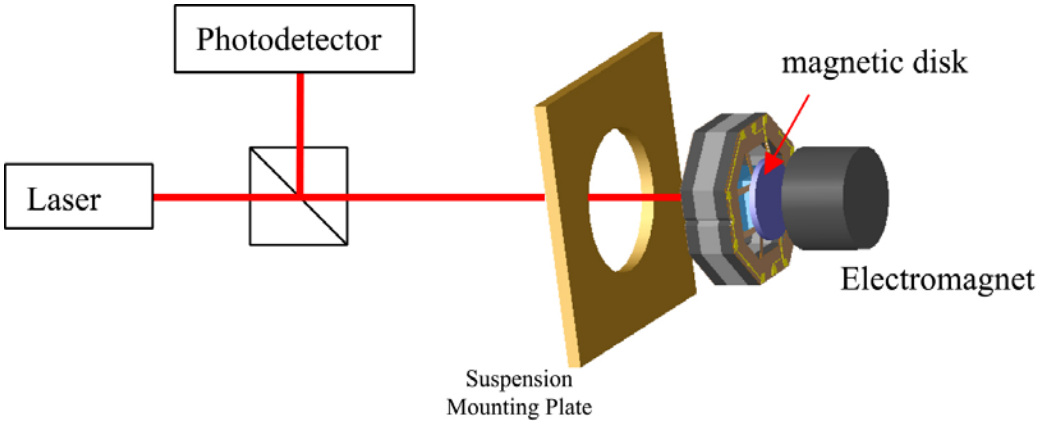


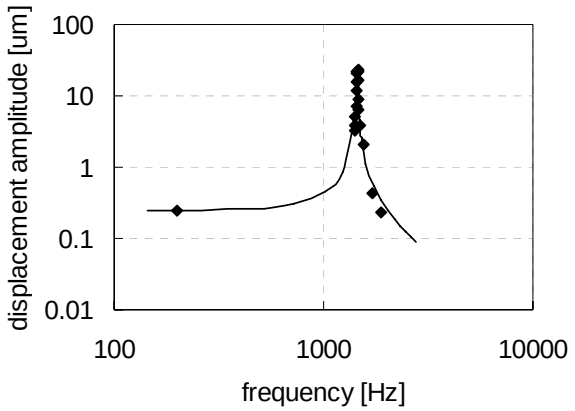


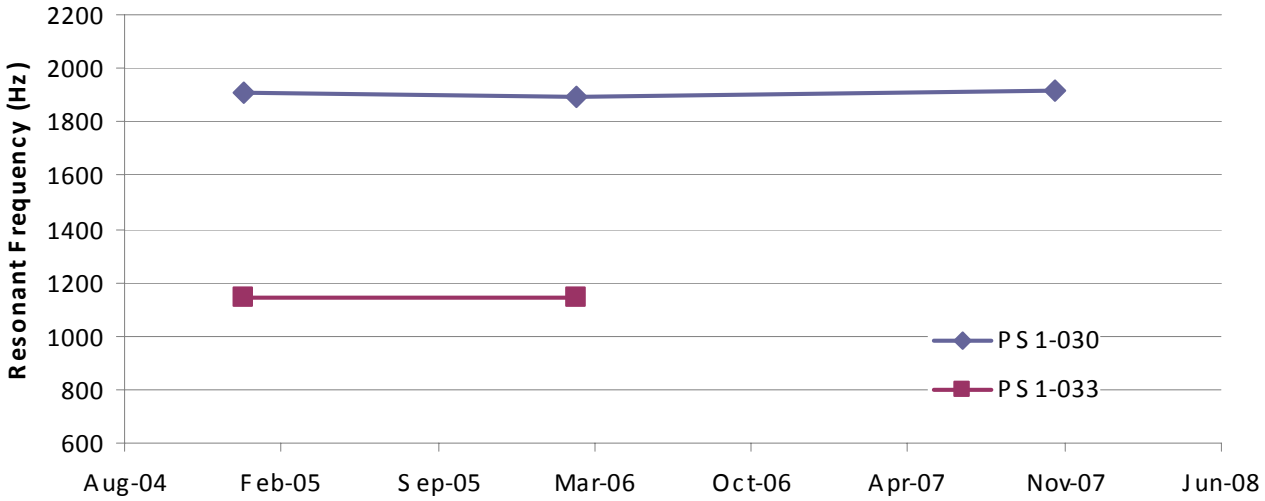
Lifetest Rack

Sandia National Laboratories

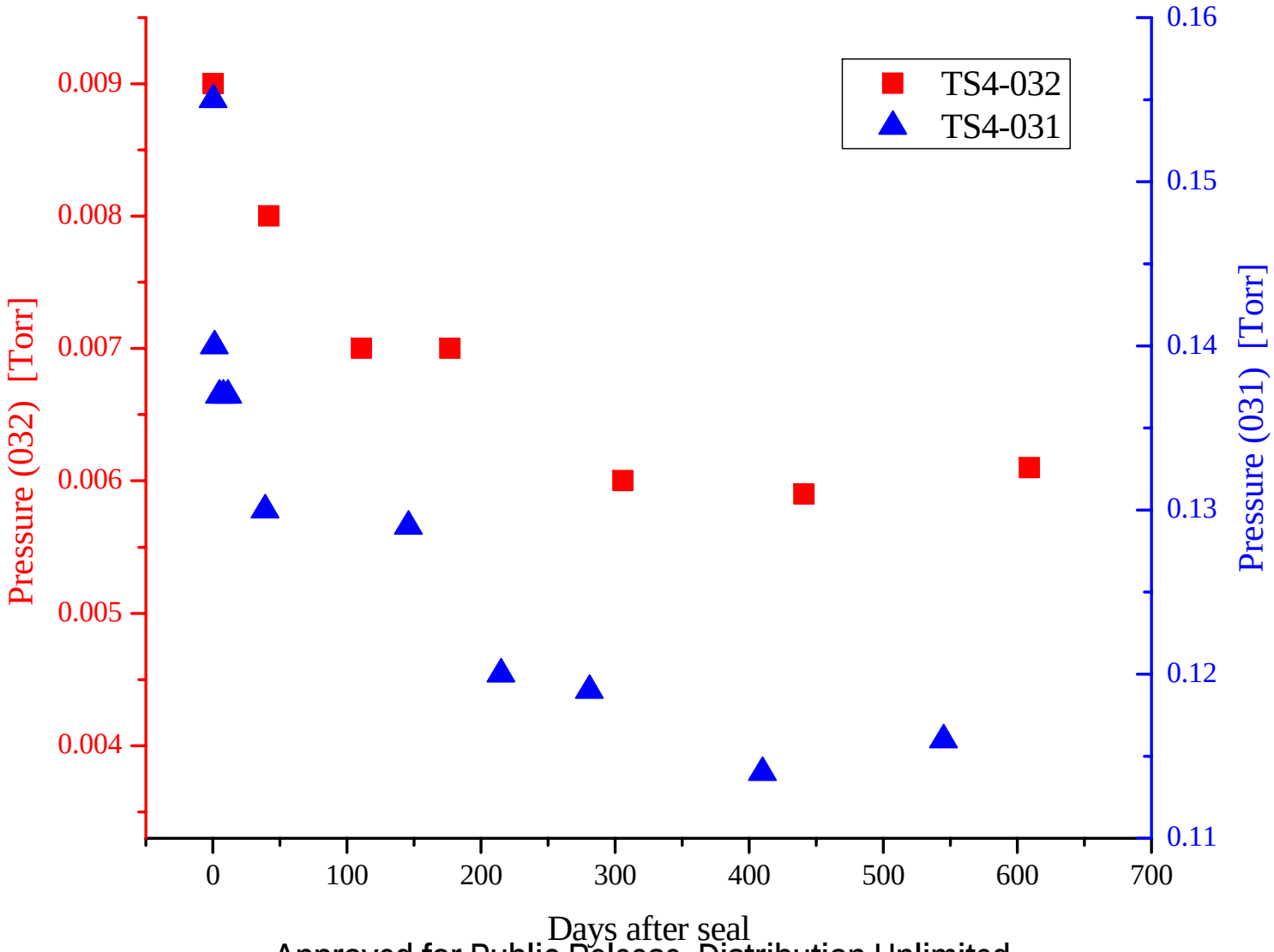
Mechanical Resonances of Physics Package



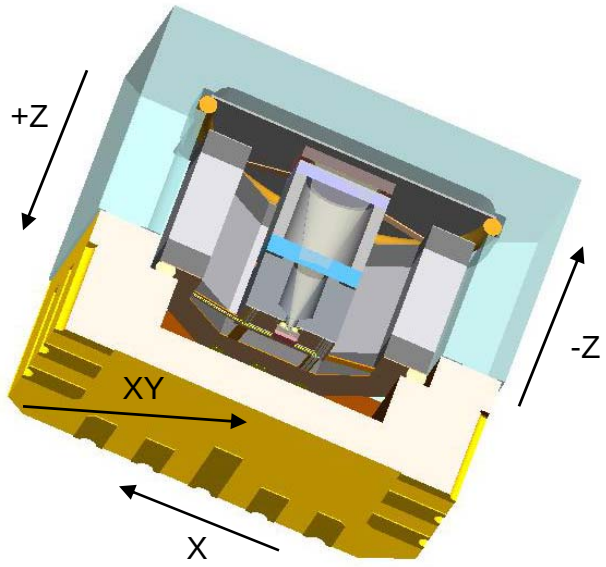




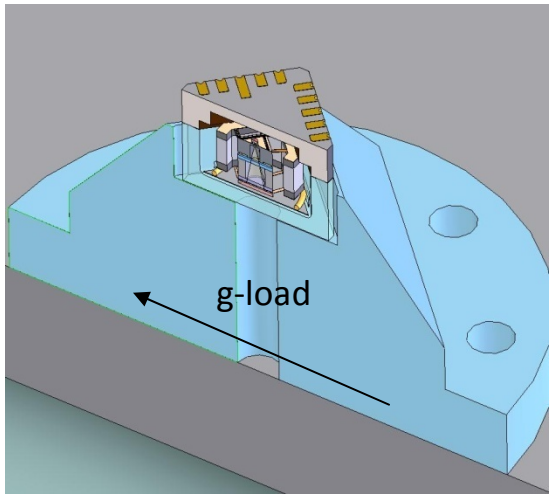
Vacuum Integrity ("Power aging")



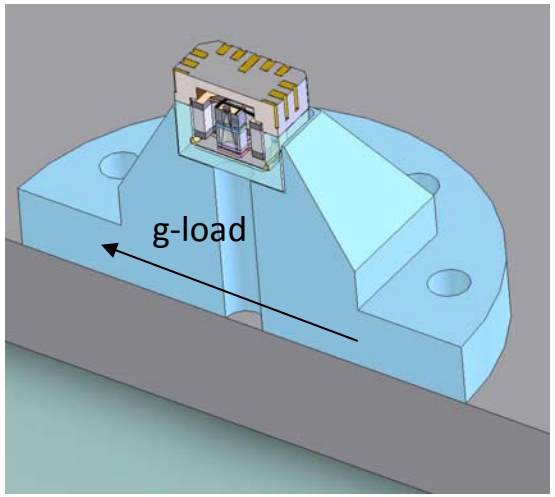
Physics Package Shock Testing



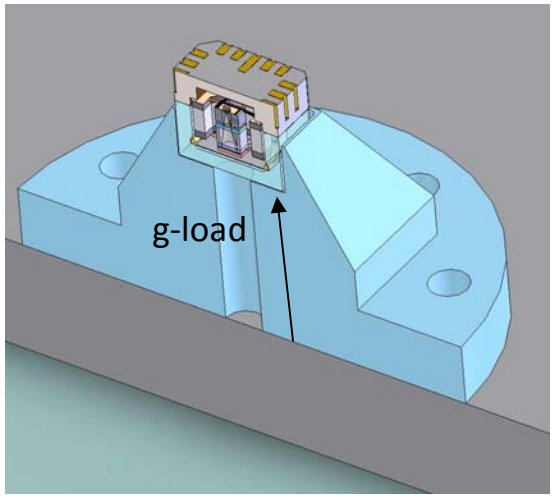
- ▶ Mil-STD- 202G, Method 213 Test conditions A – F
- ▶ 3 iterations per test condition, Seven devices tested total
  - ▪ 1 ms half-sine shock pulse @ 50,75,100,500,1000 g's
- ▶ Initial Testing (2 devices)
  - ▪ Full function after 500g test on all axes
  - ▪ Full function after 1000g test on X, XY and +Z axis
  - ▪ Partial function failure after –Z axis 1000g test
- ▪ Subsequent testing (5 additional devices)
  - ▪ Full function after 500 g test on all axes
  - ▪ 100% failure at 1000 g on any axis



X-Y shock

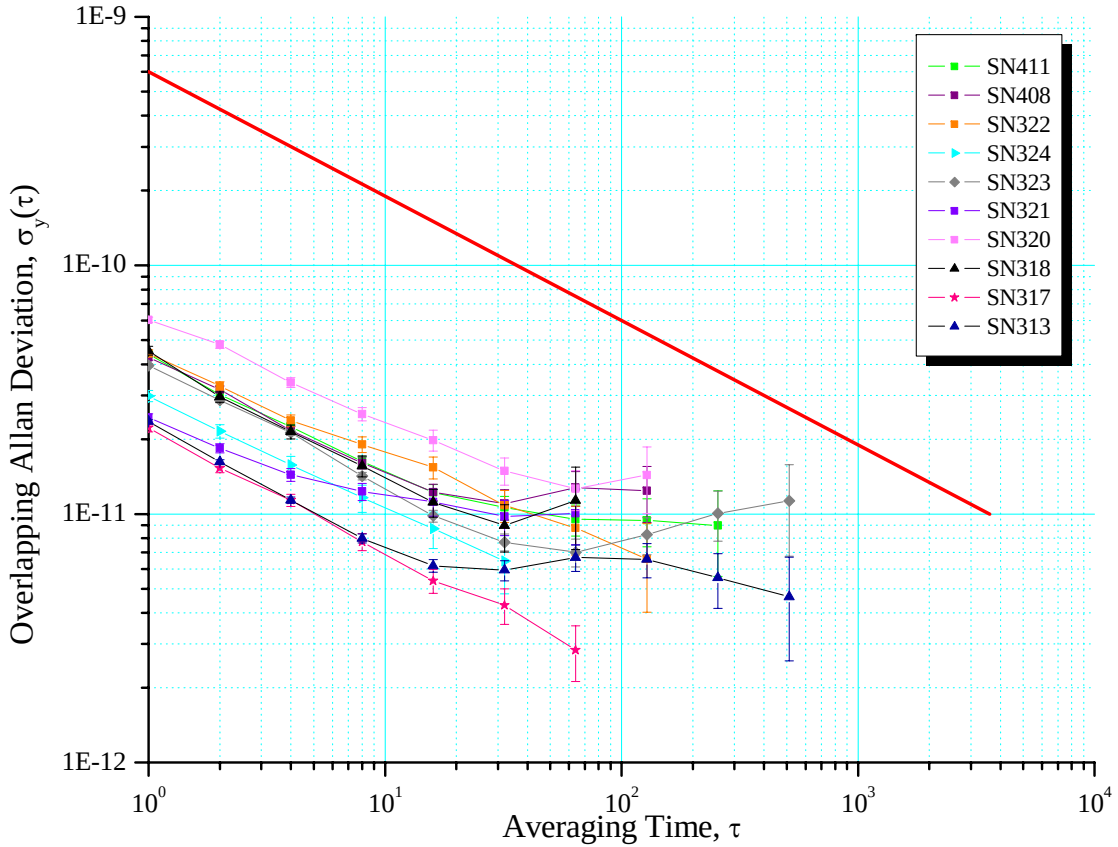


X shock



Z shock

Physics Package Performance

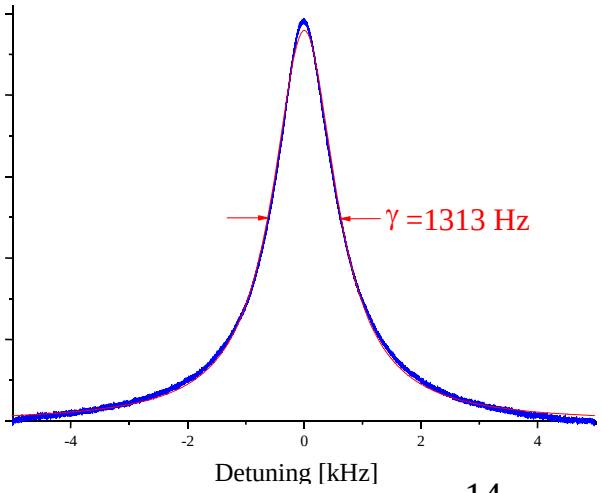


10 Phase-III physics packages

Stability measured with (optimal) laboratory electronics

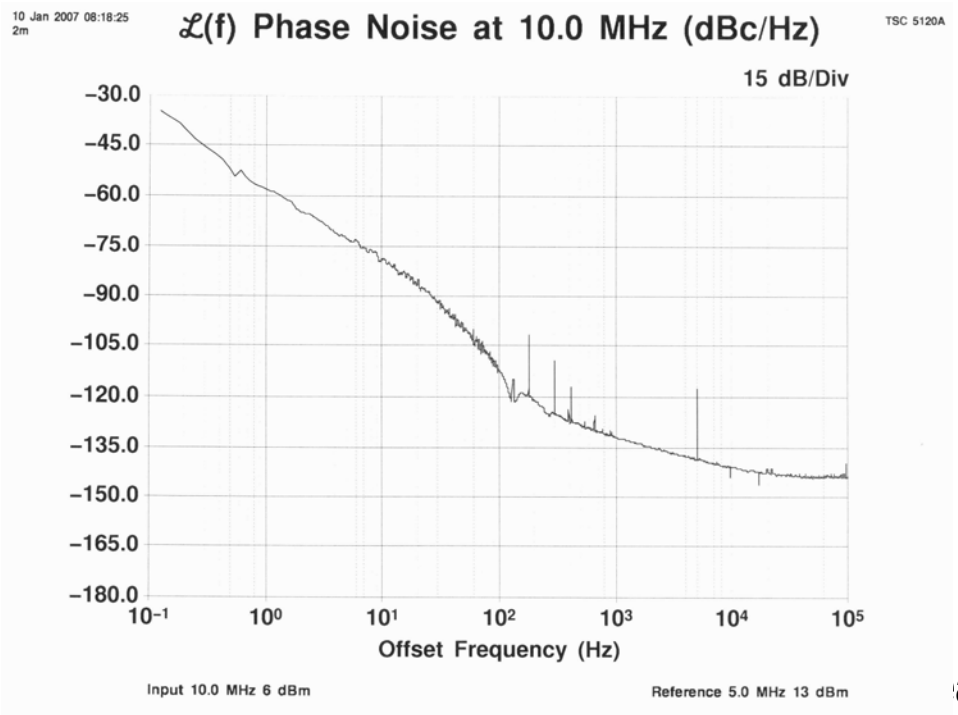
Typical is $\sigma_y(\tau) = 2\text{-}4 \times 10^{-11}\ \tau^{-1/2}$

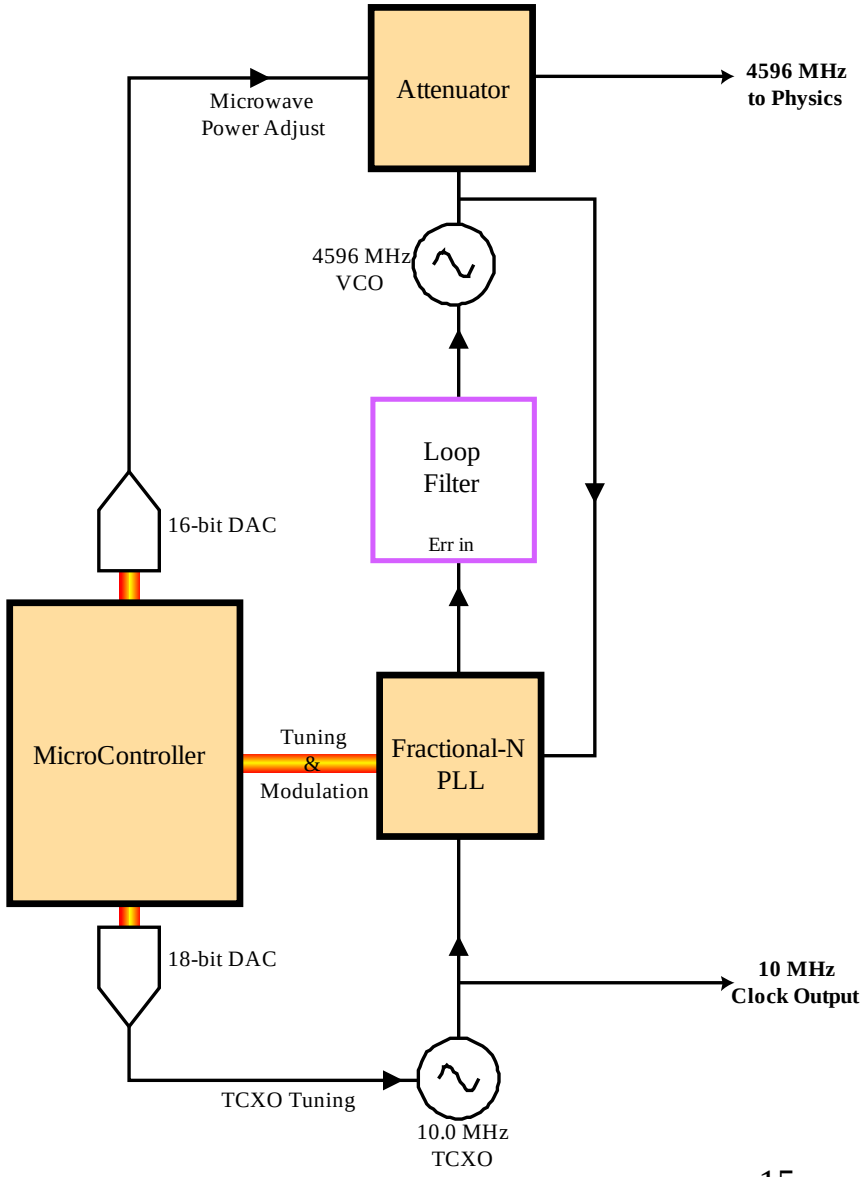
CPT Resonance



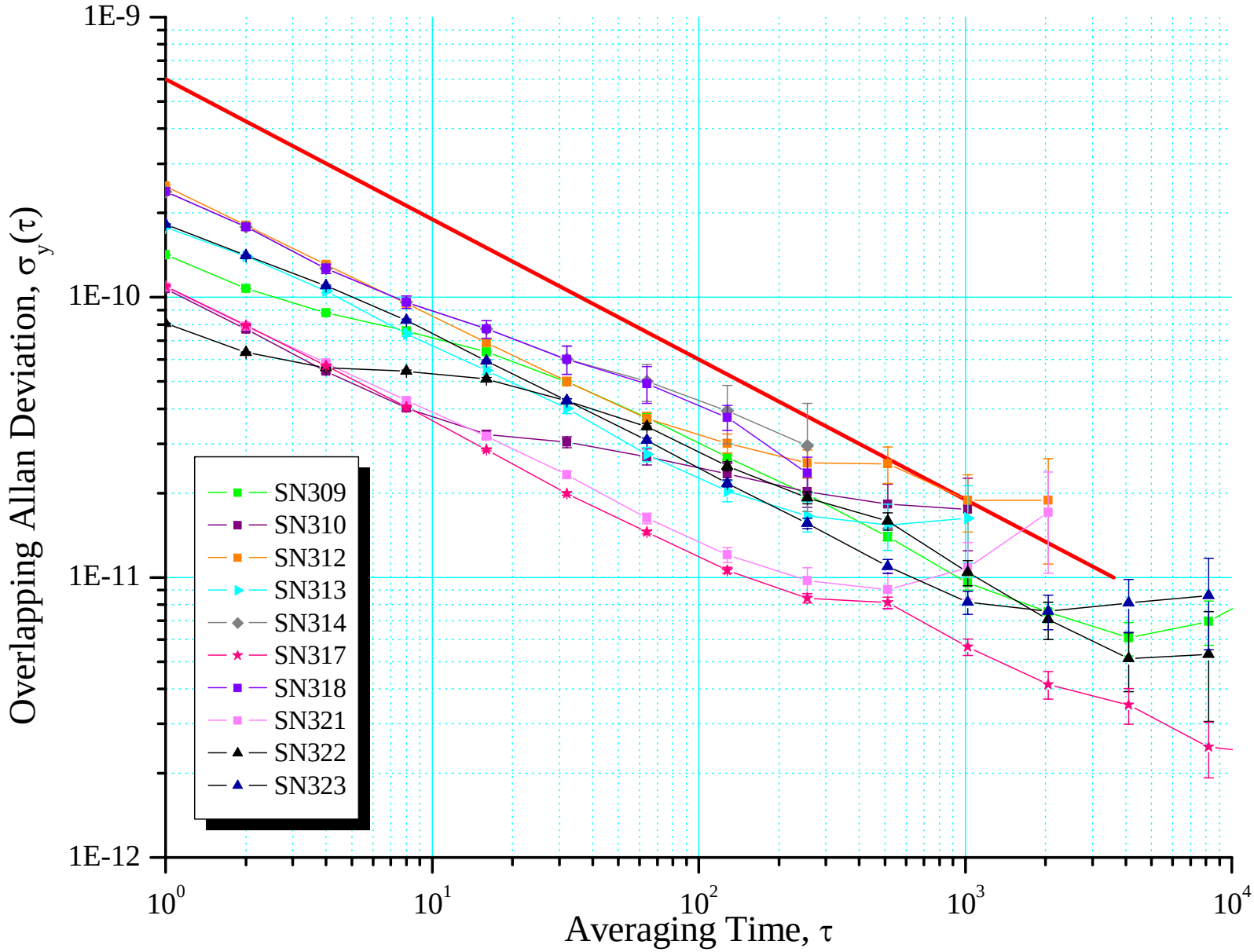
Microwave Synthesizer

- Modulation via digital control of PLL
- Tuning via digital control of PLL
  Resolution: $2x10^{-12}$
- Output is 10.0 MHz
- Power adjust 0 to -10 dBm

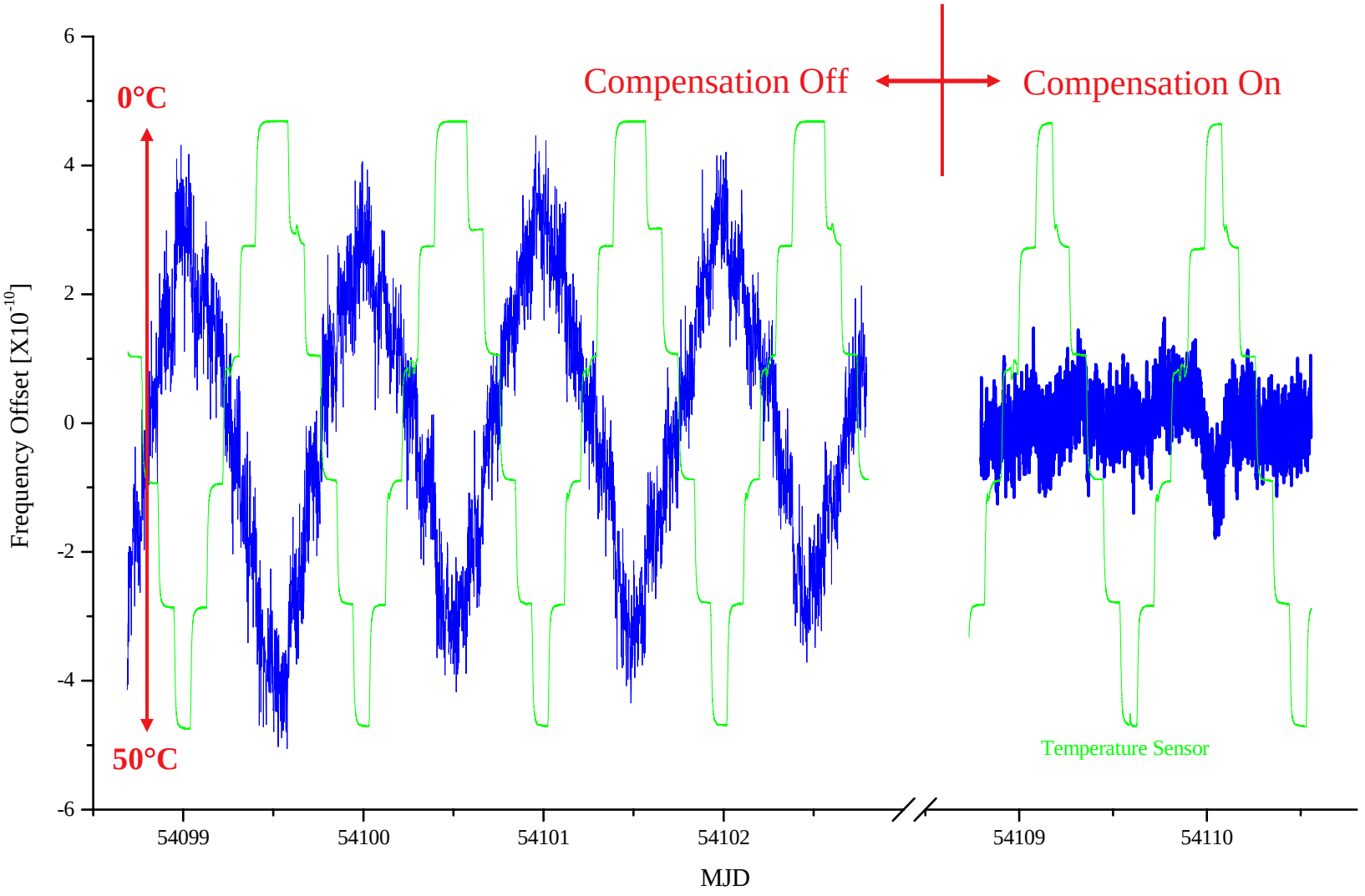




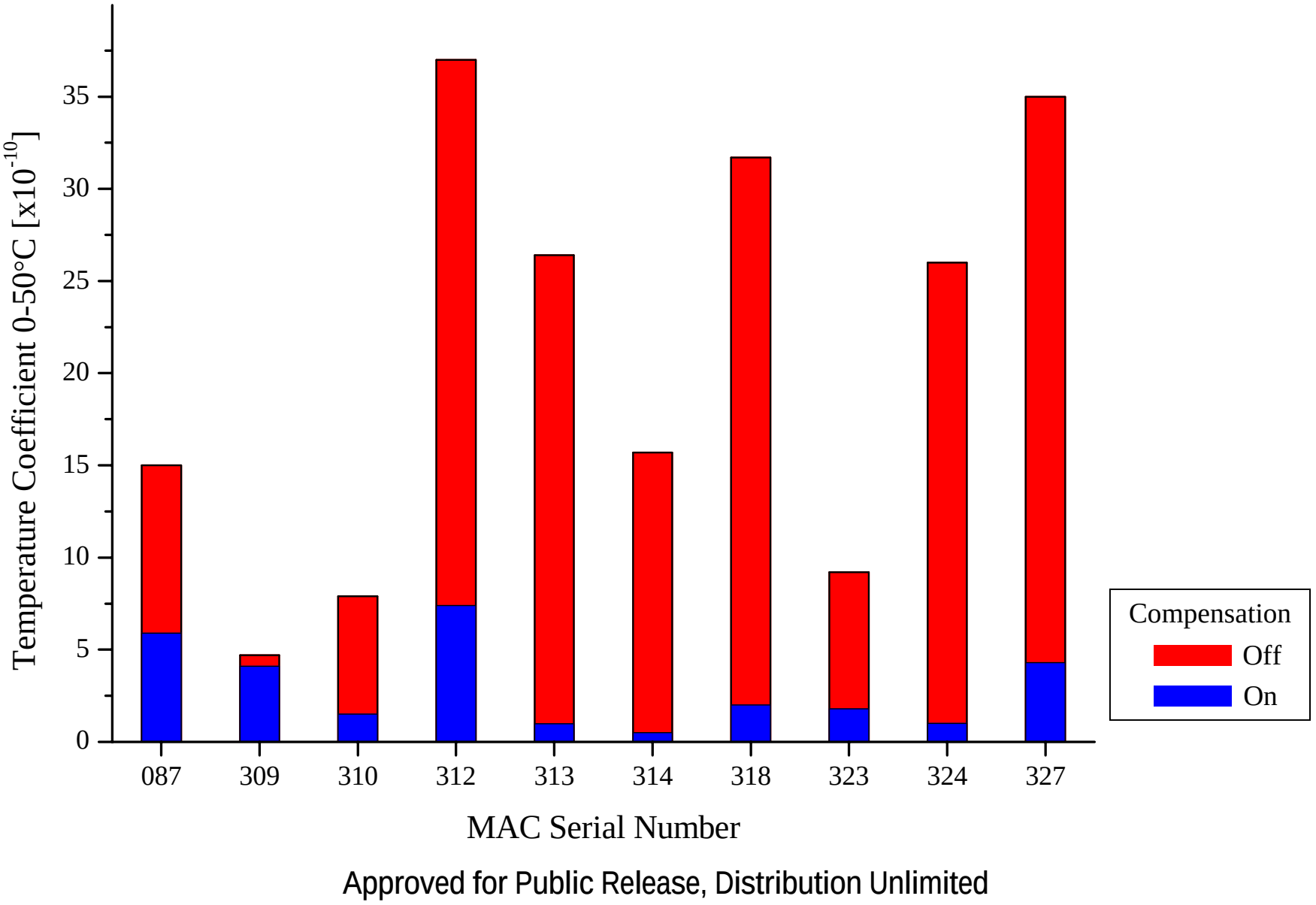
Short-Term Stability of 10 Prototypes



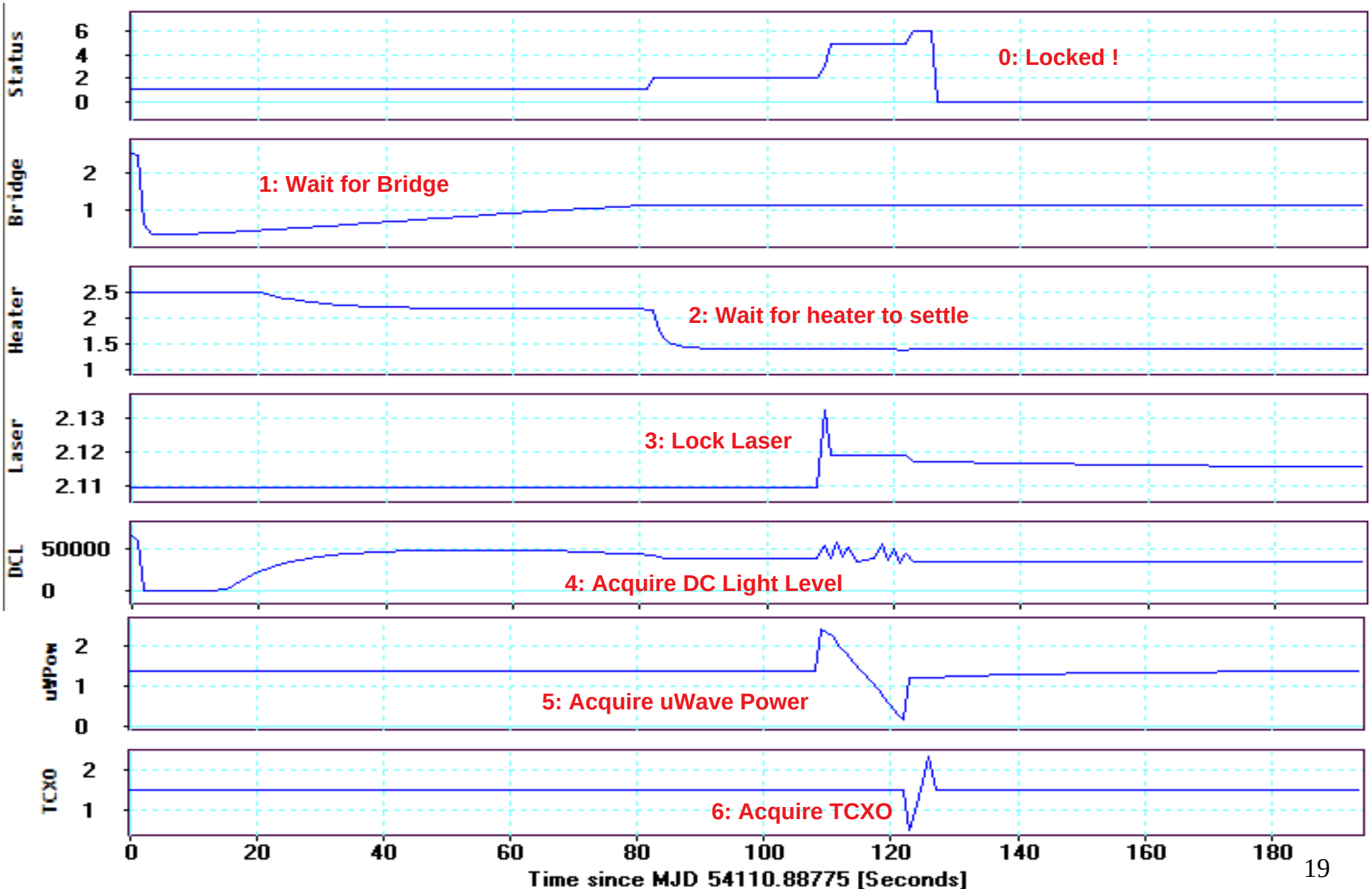
Digital Temperature Compensation



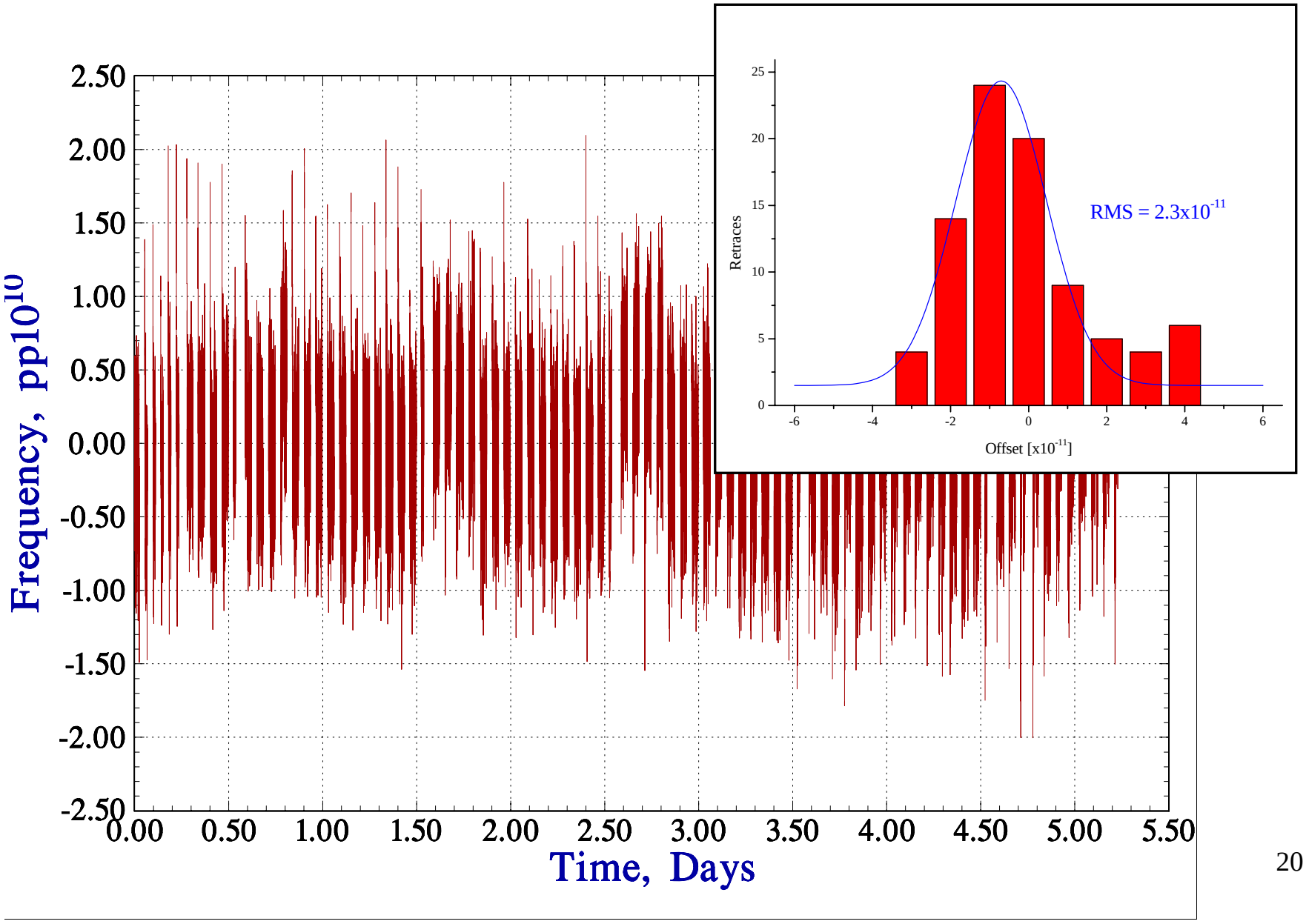
Temperature Compensation



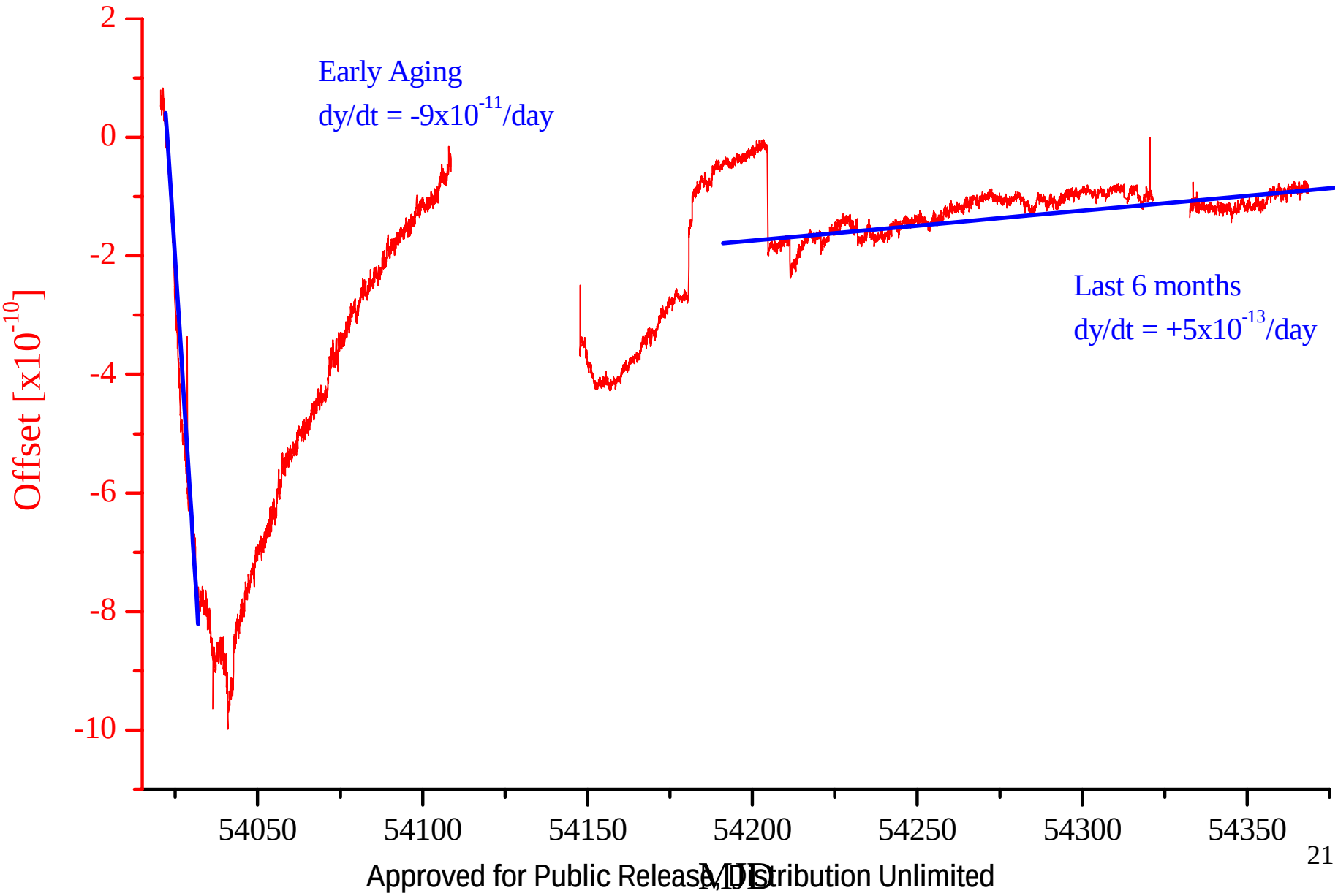
Acquisition



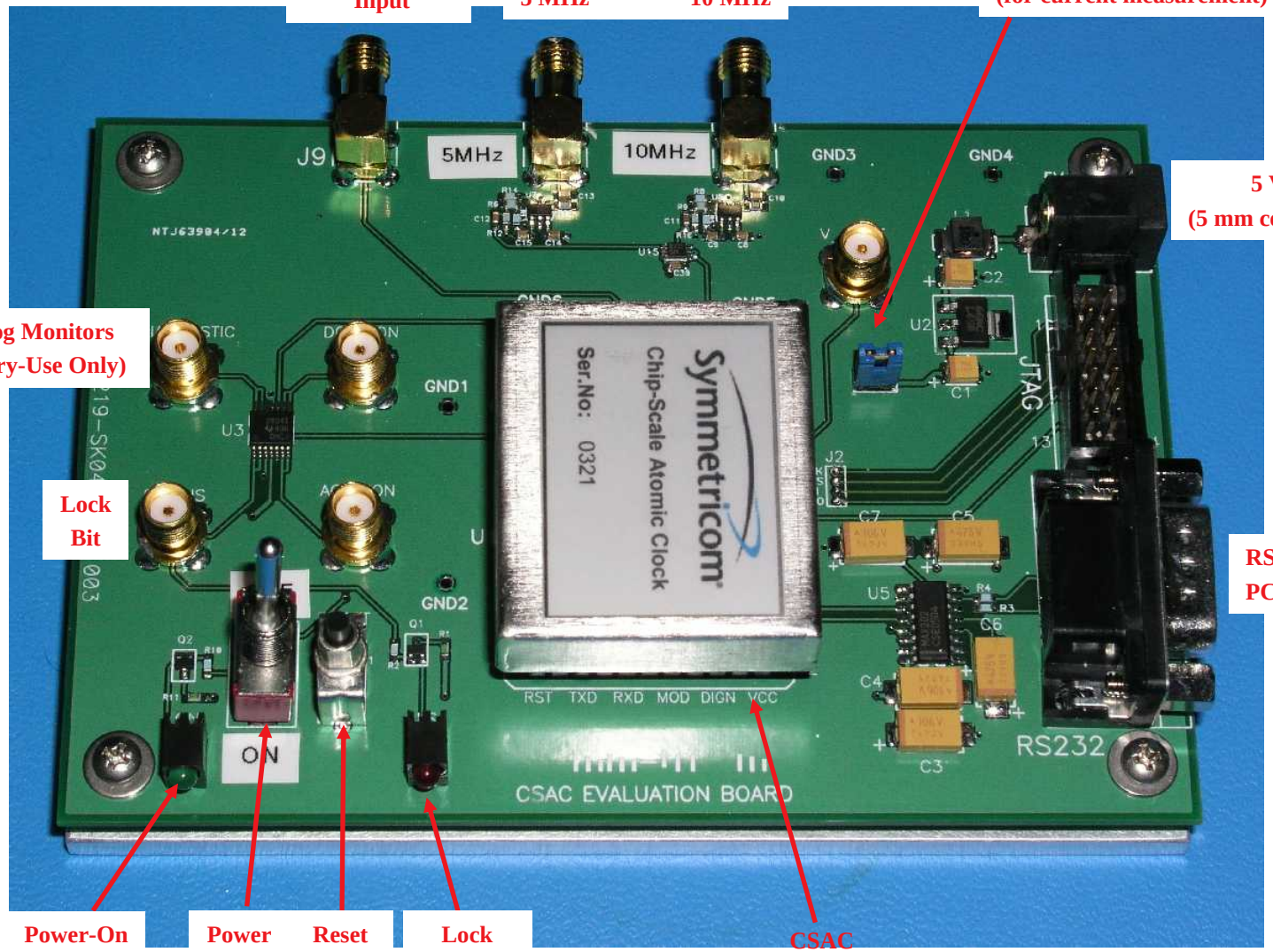
Retrace


Frequency, pp10^10
Time, Days
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
Retraces
Offset [x10^-11]
RMS = 2.3x10^-11
25
20
15
10
5
0
-6
-4
-2
0
2
4
6

SN084 Aging Data

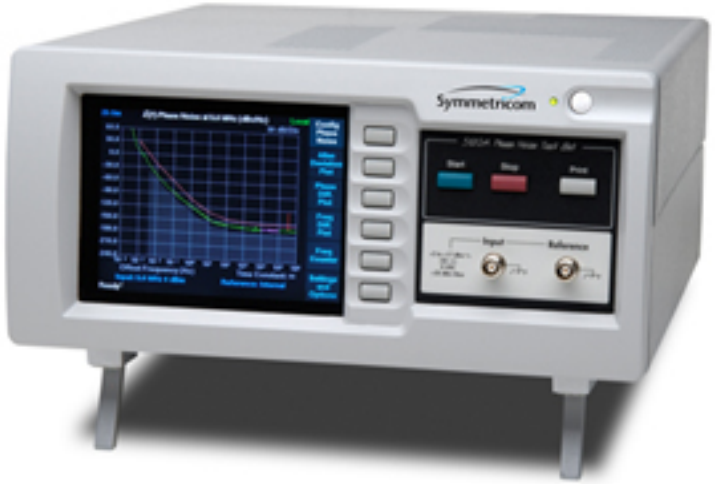


Prototype CSAC on Evaluation Board



Metrology

Active Hydrogen Maser



Stability Test Set

Cesium Beam Primary Clock

Evolution

- Low power optical sources
  - Wavelength specific
  - Linewidth constraints
- Micro-packaging expertise
  - Compatible with long life hermeticity
- Low power, low noise, microwave synthesis
  - High resolution on frequency setting (eg <1e-13)
- Atomic clock expertise
  - Metrology and measurement
  - Robust algorithms
- Low power electronics integration and packaging

The CSAC Team

Draper Laboratory: Mark Mescher, John LeBlanc, Gary Tepolt, and Mat Varghese
Symmetricom: Peter Vlitas, Robert Lutwak, Mike Garvey, and Ahmed Rashed
Sandia: Gregory Peake, Kurt Geib, and Darwin Serkland

$$$ DARPA-MTO Contract No. NBCHC020050