Development of a Prototype Atomic Clock to Observe and Characterize Coherent Population Trapping

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Acknowledgements

- Irina Novikova
- Eugeniy Mikhailov
- Charles Center

Outline

- Motivation
- Background
- Hardware
- DAVLL
- Crystal Oscillator
- Results
- Future Work

Motivation

- Two companies and National Institute of Standards and Technology have created sub-cubic centimeter atomic clocks
- We want to create a prototype atomic clock to emulate their clocks and find ways to improve the performance

Our Goal

- Stable lasing on rubidium transition
  - Two locking systems
- Modulation of laser in rf regime
  - Crystal oscillator
- Observe Coherent Population Trapping (CPT) in rubidium vapor cell
- Study, characterize, optimize CPT

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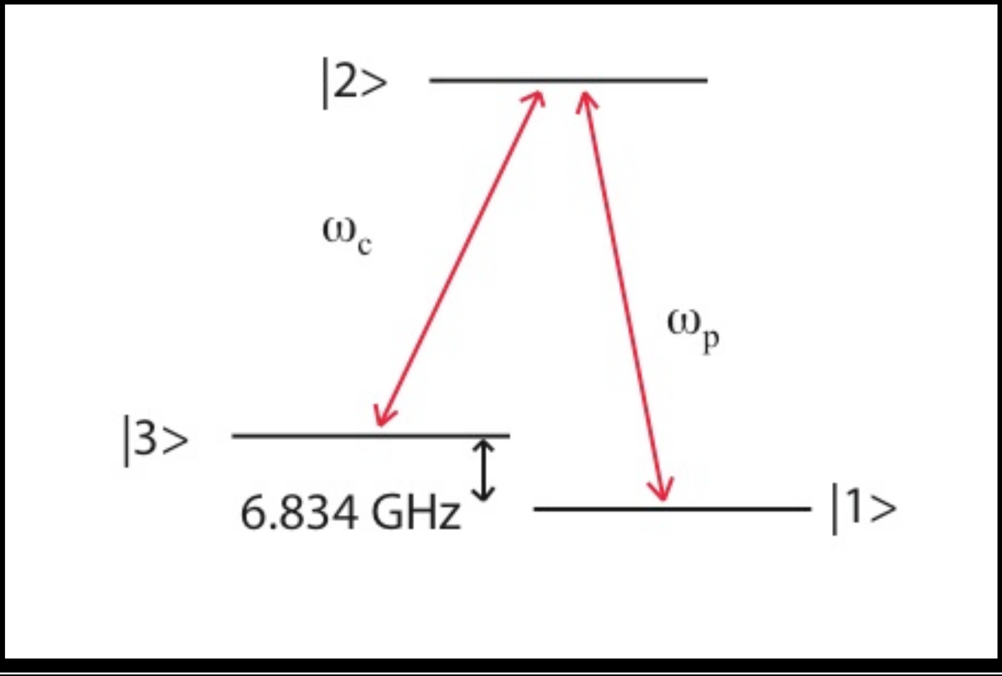
Background

- Atomic transition in rubidium-87
  - 5S_1/2 to 5P_1/2



Background continued

- Lambda system requires two electromagnetic fields at different frequencies
- Problem: inherent in lasers are small random shifts in frequency around a set frequency (“jumps”)
- Bigger problem: if two lasers are physically separate, the “jumps” are random

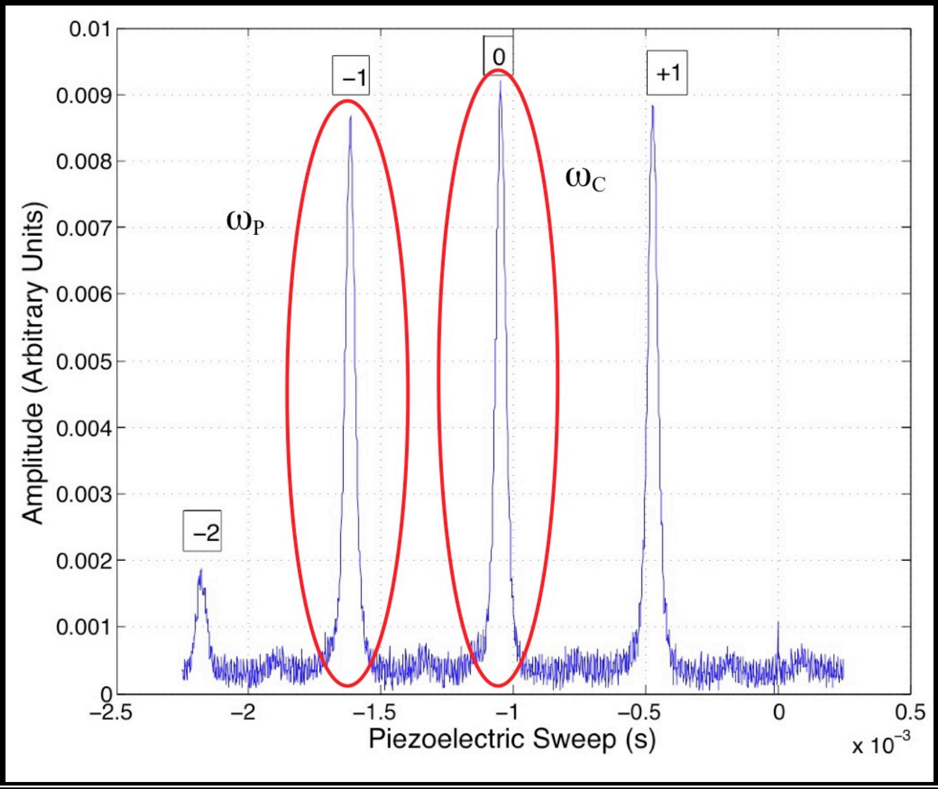
Background continued

- Solution: use phase modulation to create two fields out of one physical laser
- Why? Both fields "jump" with each other so relative frequency can be set by external generator
- Creates carrier with sideband comb

Background continued

- Carrier to sideband spacing determined by input frequency

$$E = \sum_{n=0}^{\infty} E_0 J_n(\varepsilon) e^{ikx - i(\omega - n\omega_m)t}$$



Background continued

- Use coherent population trapping to measure transmitted light
- The closer to hyperfine splitting resonance, the more transmission
- Counter locked to maximum transmission which corresponds to clock frequency

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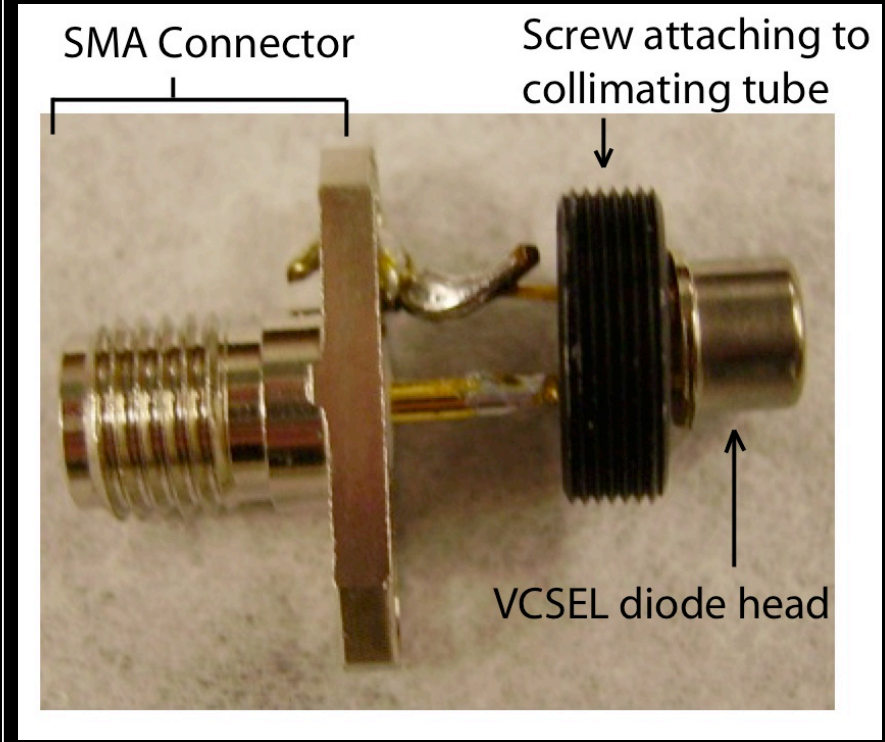
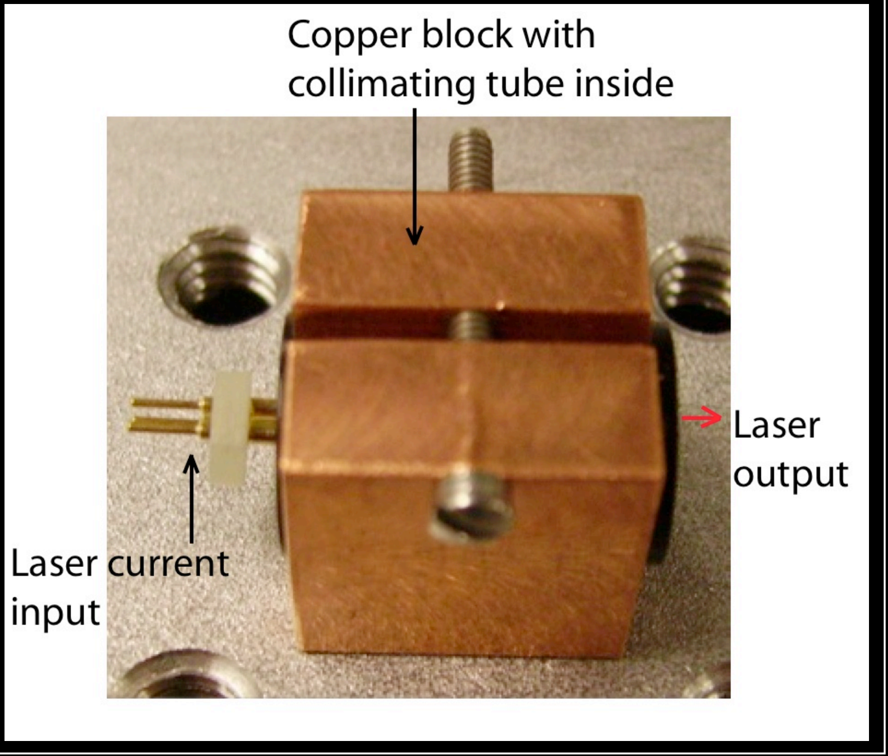
Hardware

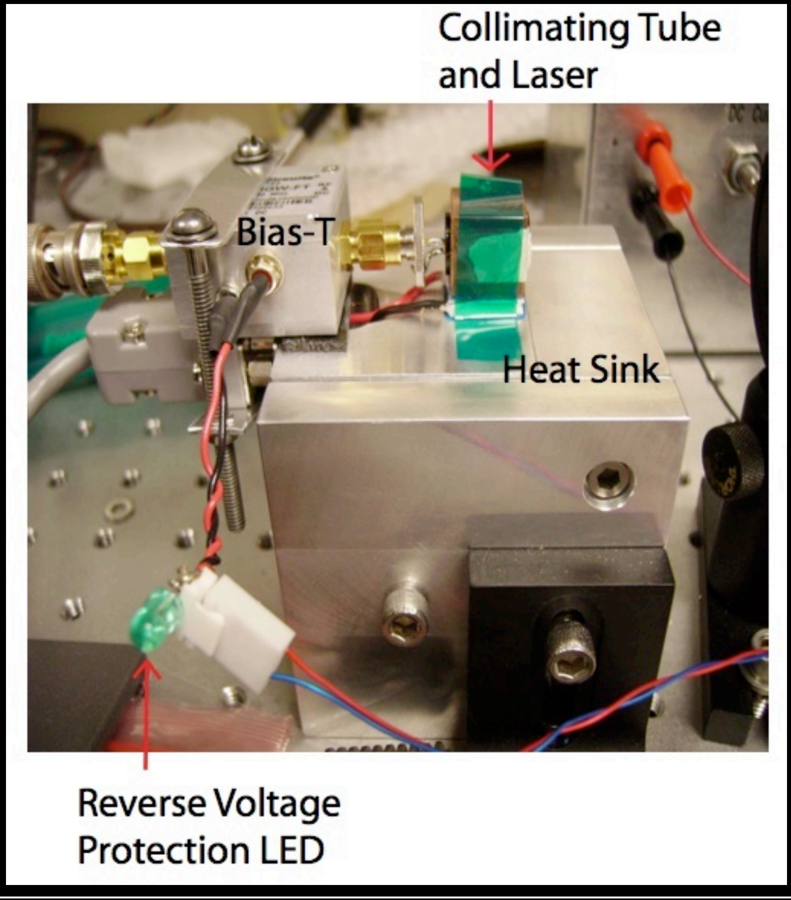
- VCSEL





Hardware continued

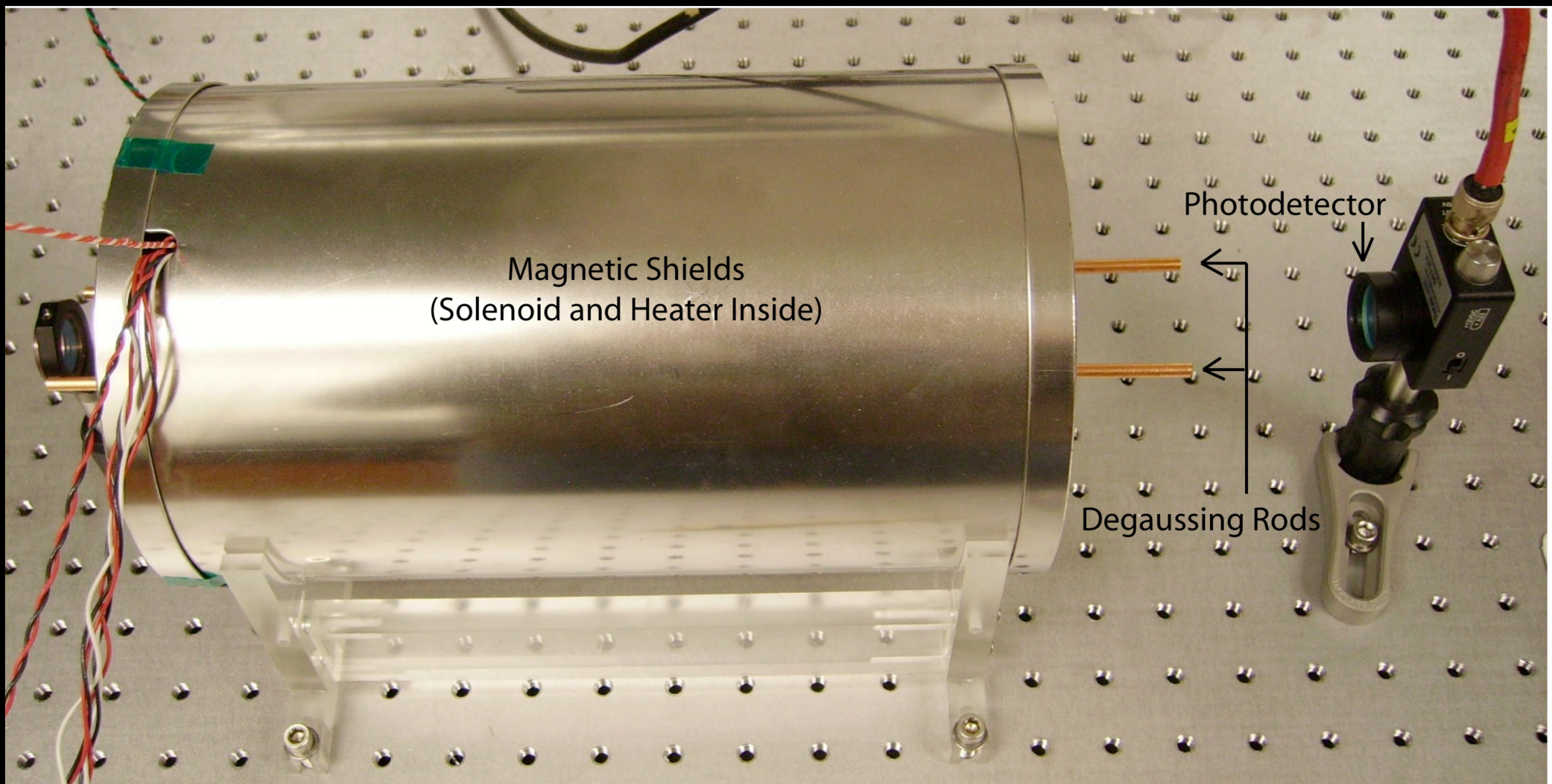
- Temperature stability



Hardware continued

- Solenoid and shields
  - External non-homogeneous fields that interact with vapor cell, shifting state frequencies
  - Need to control field vapor cell feels, so surround cell with solenoid to produce constant homogeneous magnetic field and shields to limit outside magnetic fields

Hardware continued



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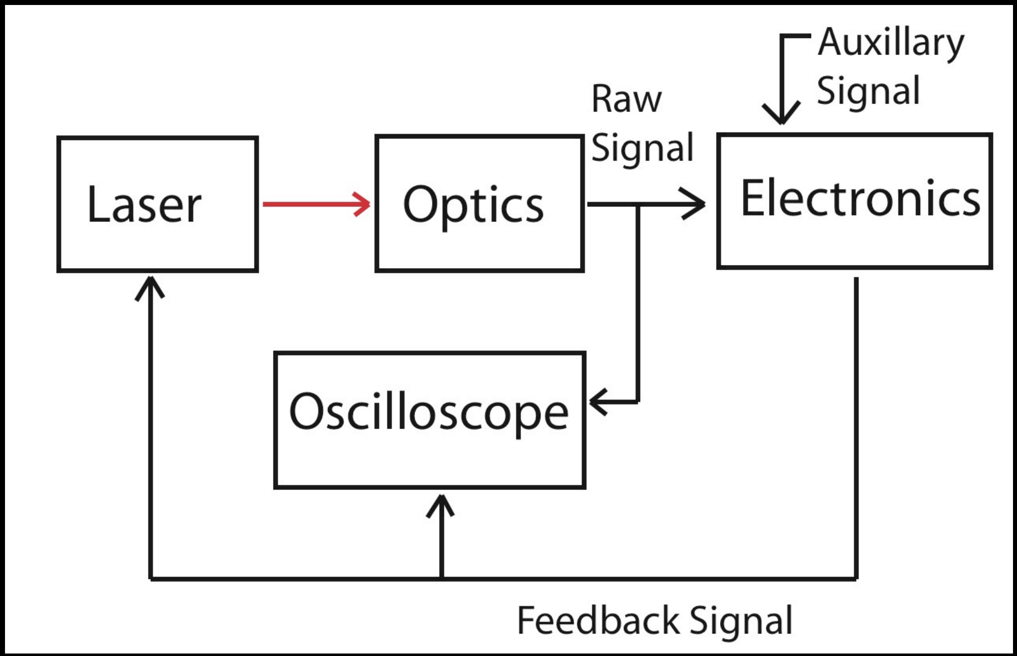
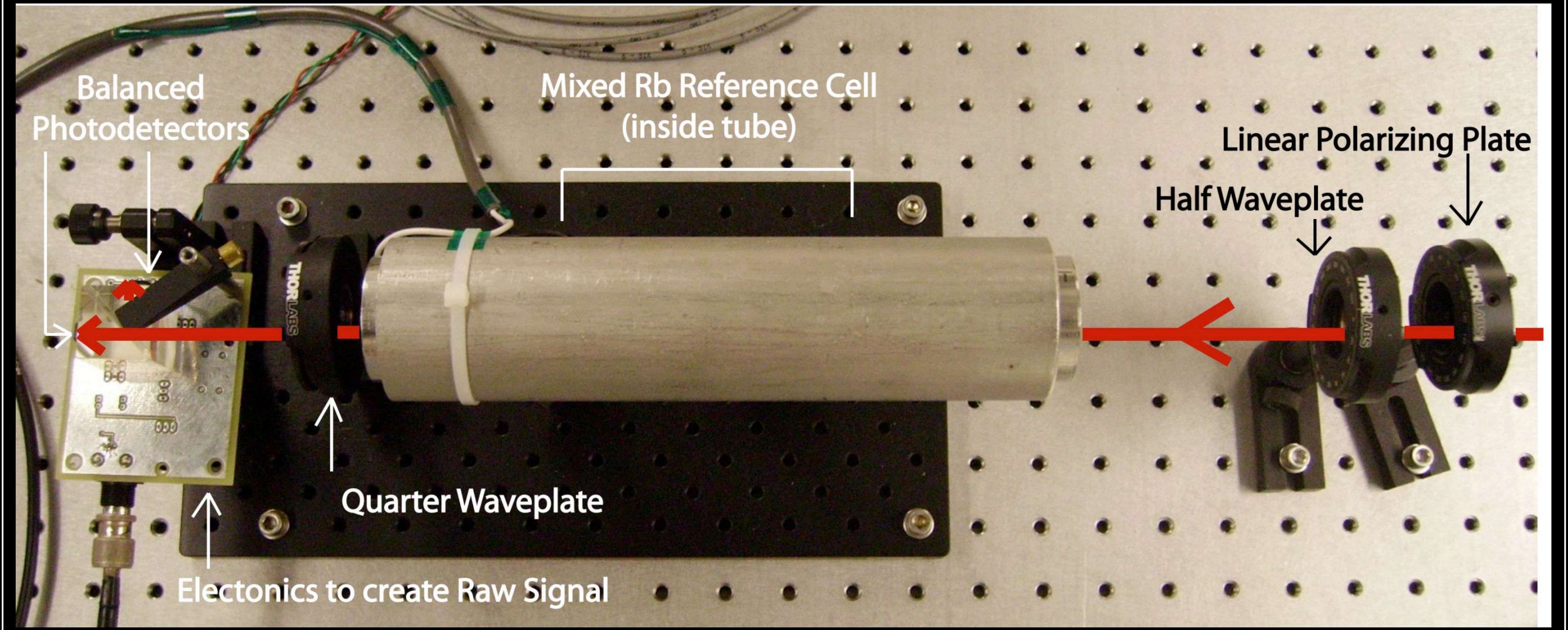
DAVLL

- Allows locking of frequency of VCSEL to specific rubidium resonance frequency



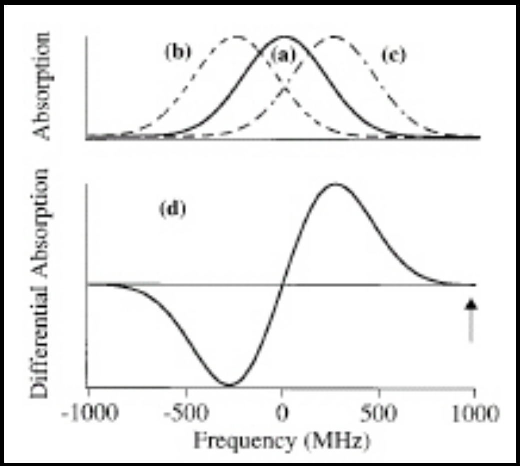
DAVLL continued

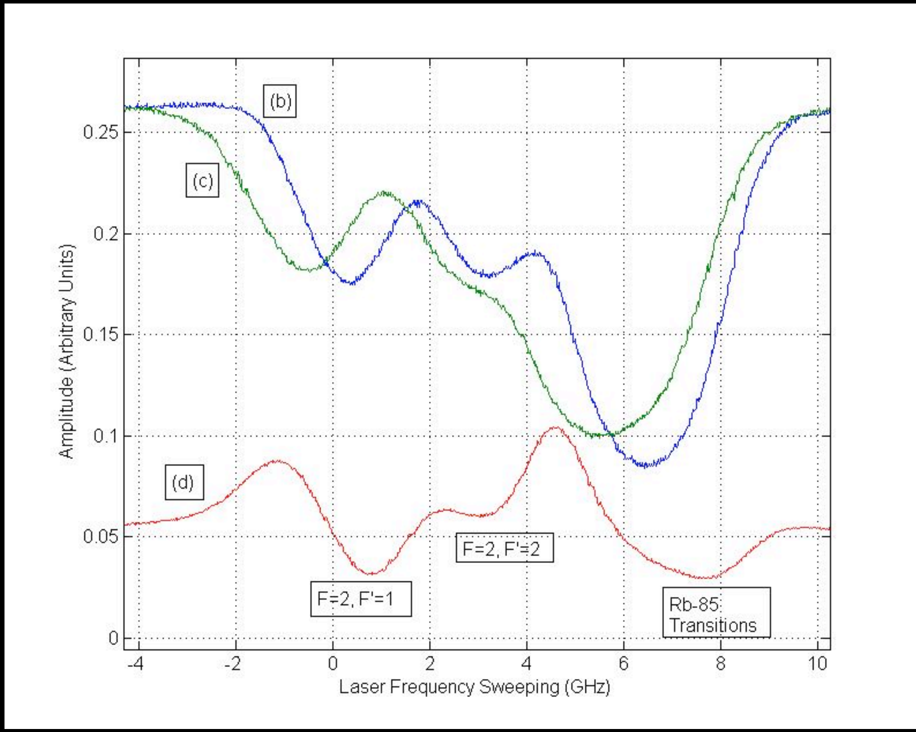
- Optical hardware



DAVLL continued

- Absorption and differential spectra





DAVLL continued

- Electronics are used to amplify the raw signal from the optics and adjust the current to the laser accordingly
- Example: if laser's frequency is higher than zero point on raw signal, electronics will supply less current so frequency decreases

DAVLL continued

- Had issues before with locking the laser's frequency to the rubidium frequency
- Now able to lock DAVLL to chosen resonance
- Developed procedure to lock DAVLL
- Still some issues with the offset of the balanced photodetectors

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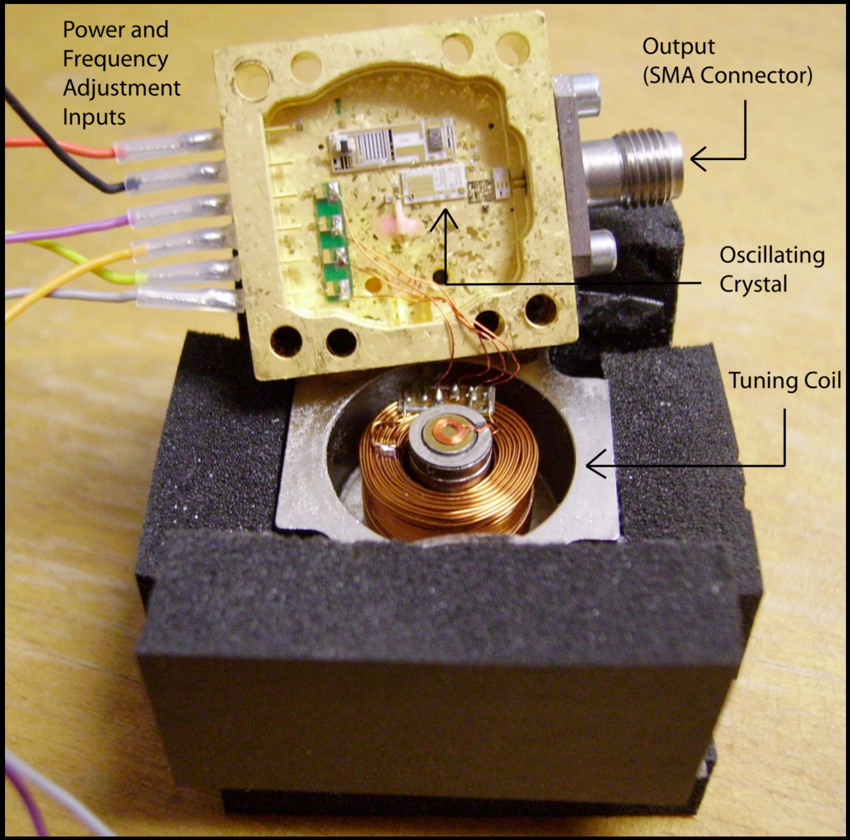
Crystal Oscillator

- Current controlled tunable crystal with frequencies ranging from 5.95 GHz to 7.15 GHz at 15 dBm
- Two constant current sources designed and built
  - One provides current to set crystal oscillator at 6.834 GHz
  - Other provides small current to tune to CPT resonance

Crystal Oscillator continued

- Inside of crystal oscillator



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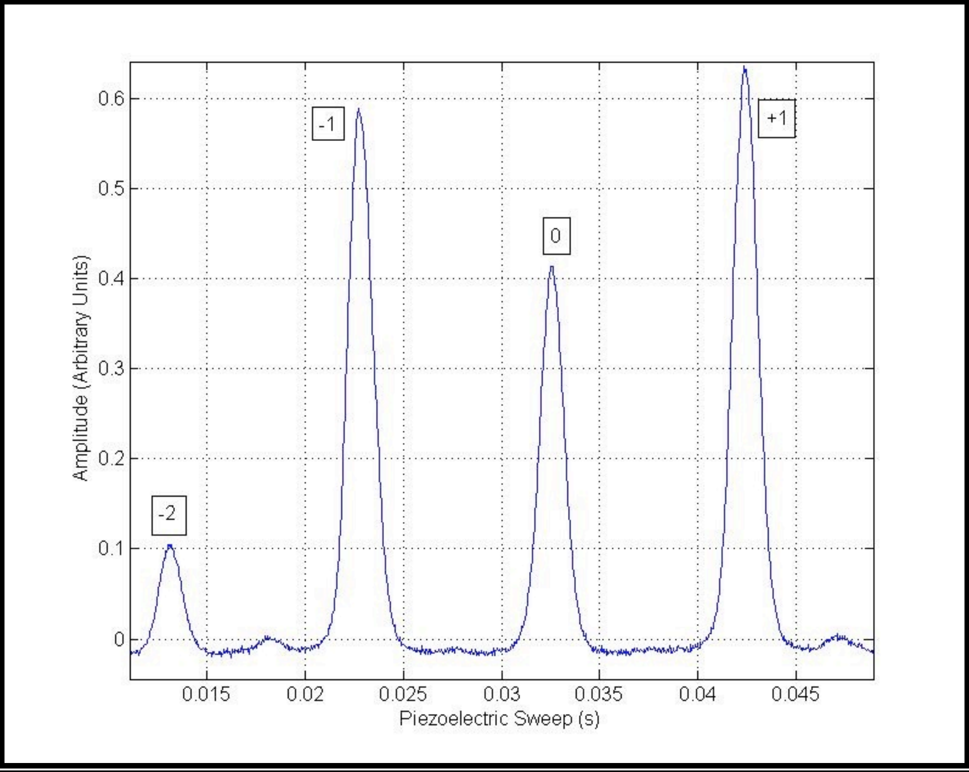
Results

- VCSEL Modulation
  - With crystal oscillator, saw sidebands greater than carrier at 15 dBm at 6.834 GHz
- Achieved CPT with crystal oscillator

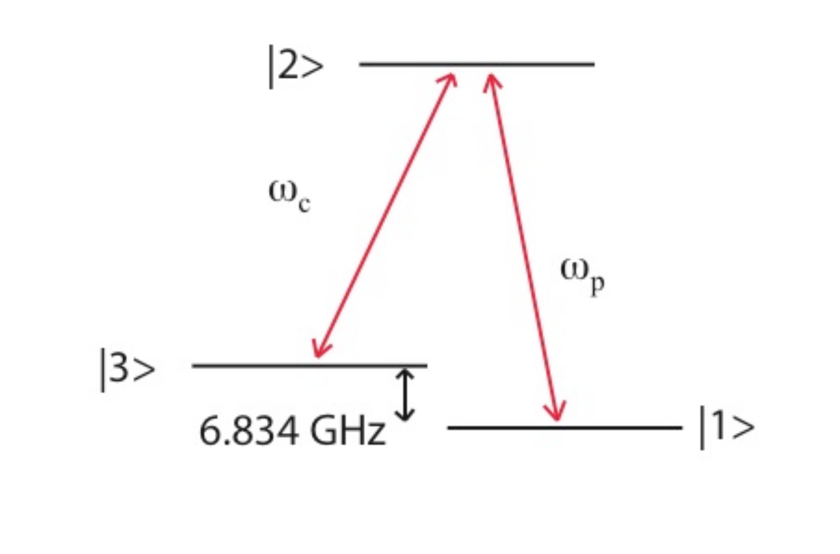
Results continued

- Crystal oscillator modulation



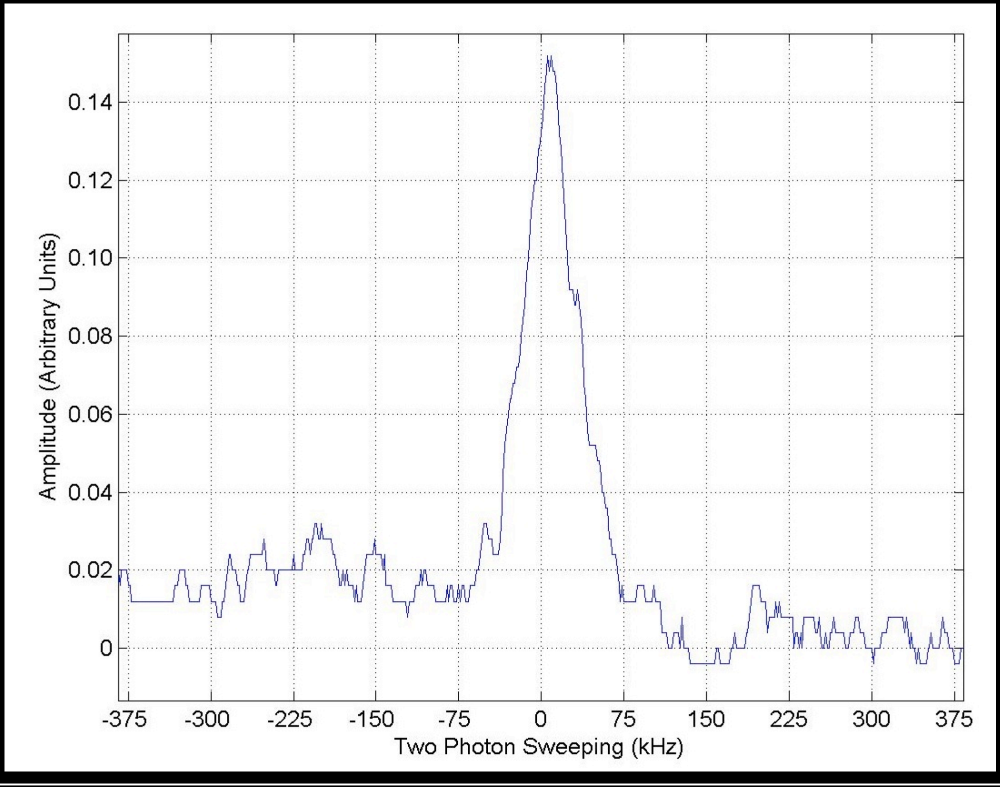
Results continued

- Coherent population trapping (CPT)
  - Occurs when all electrons are driven to ‘dark’ state that does not interact with either electromagnetic field
  - Laser has 100% transmission



Results continued

- CPT in isotopically pure cell

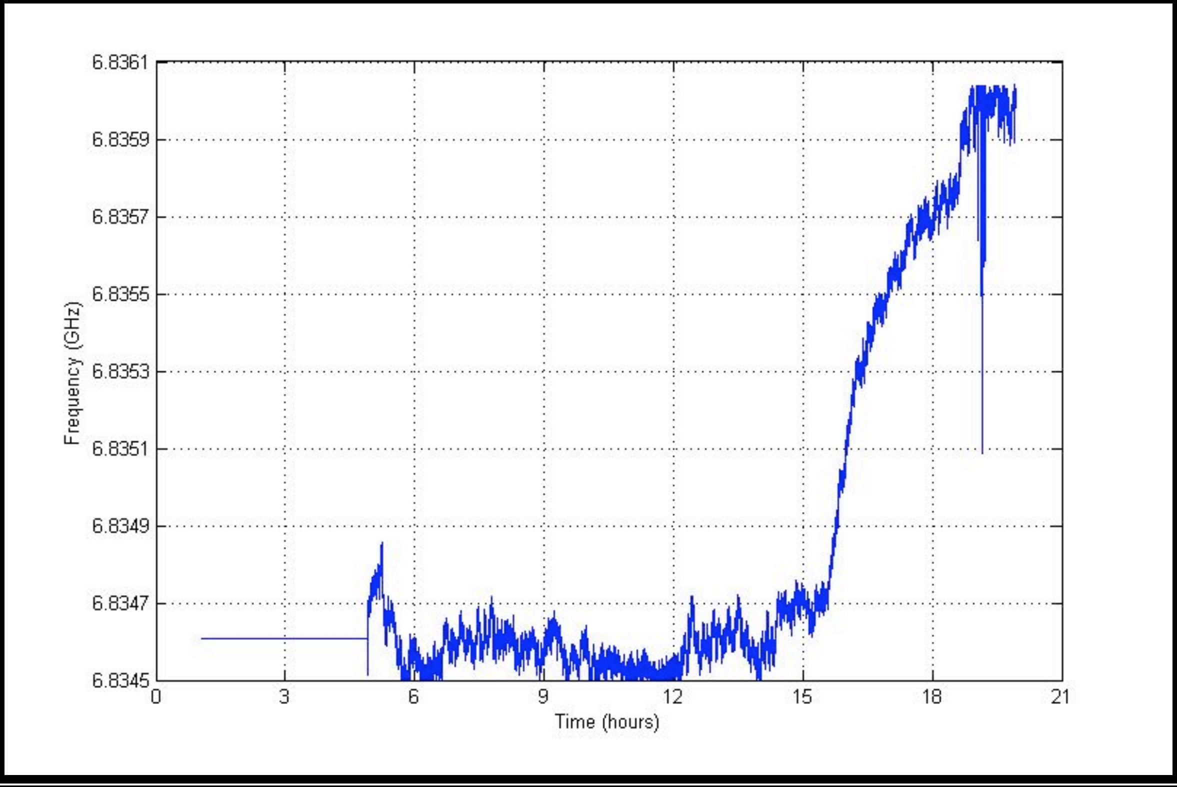


Results continued

- Locking of entire system
  - DAVLL to lock to optical resonance
  - crystal oscillator current controllers to lock to CPT

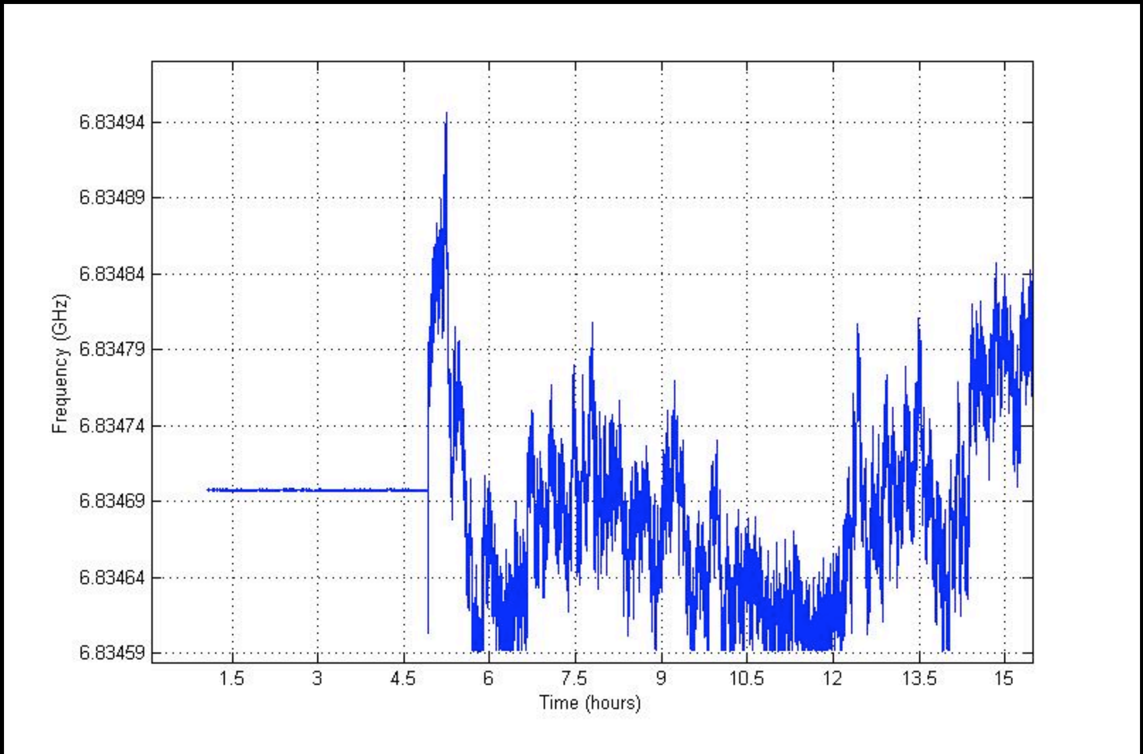
Results continued

- First recognition of clock locking



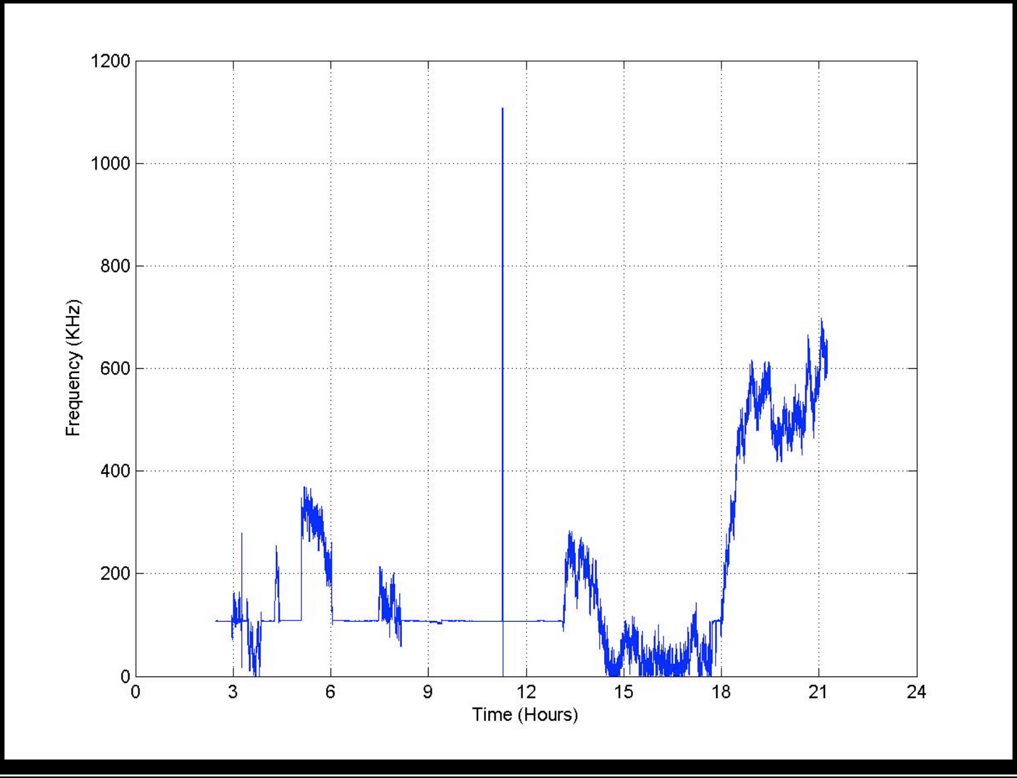
Results continued

- First attempt zoomed in



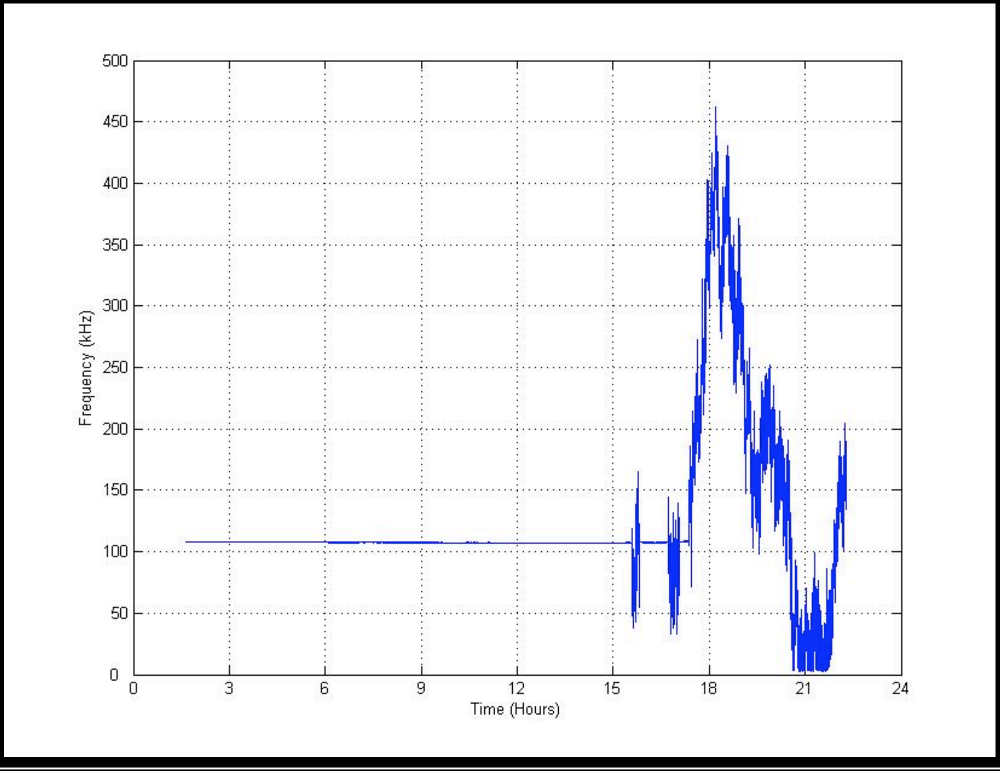
Results continued

- Second attempt at locking



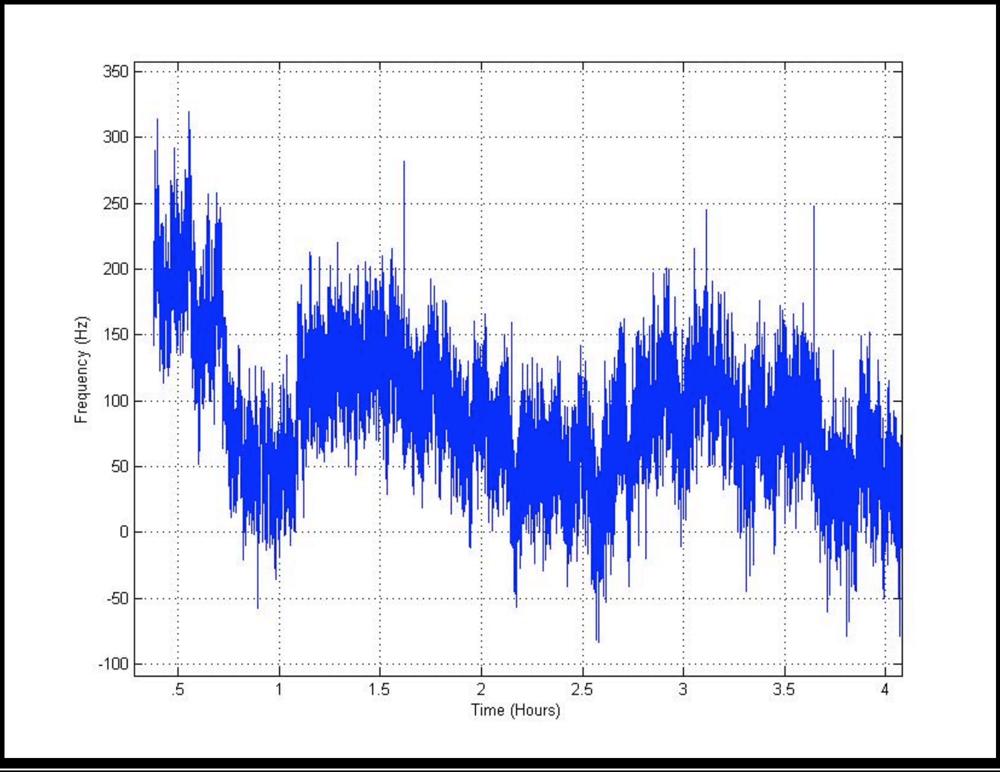
Results continued

- Third attempt at locking



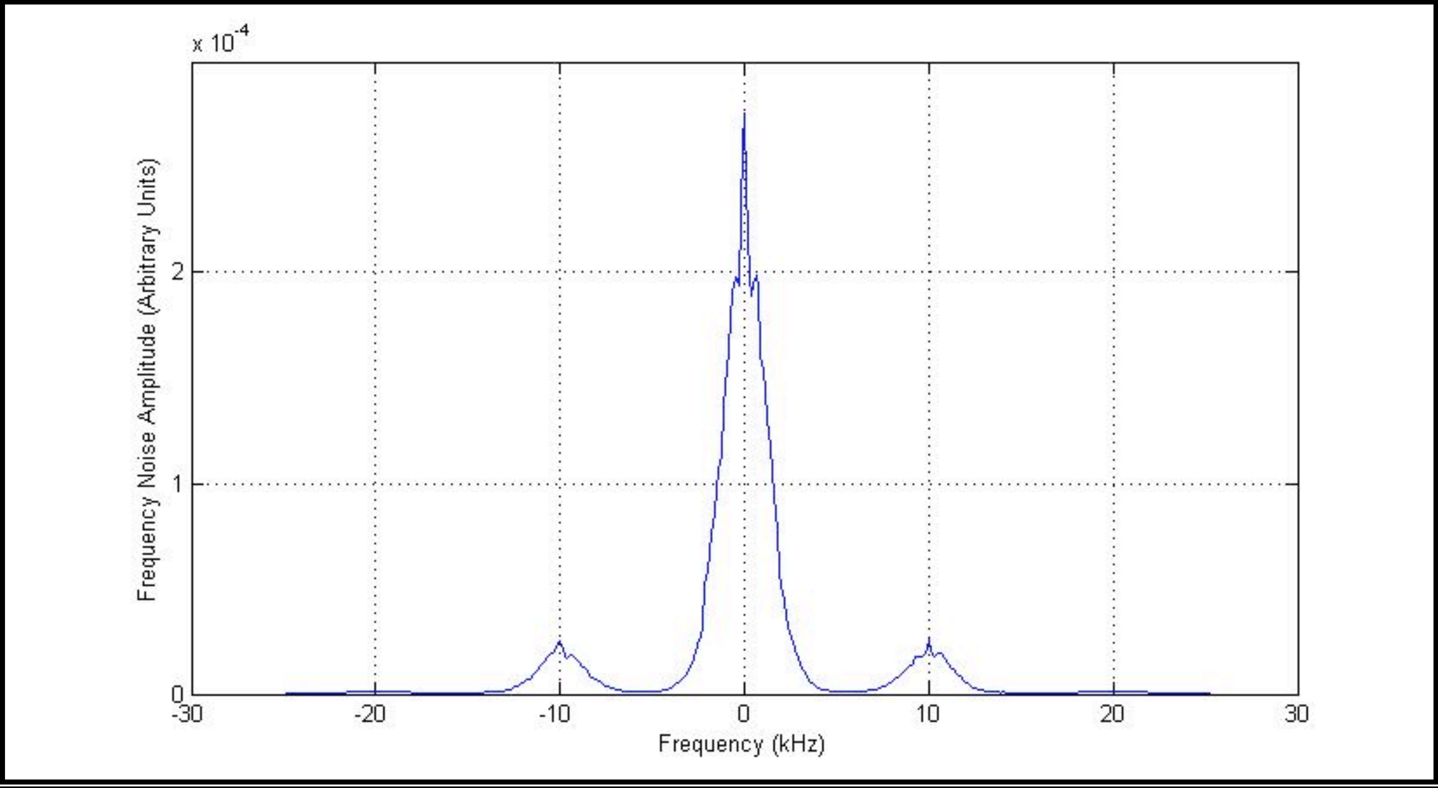
Results continued

- Third attempt zoomed in



Results continued

- Frequency noise of the crystal oscillator



Results continued

- The locking frequency has been repeatable each day to within 200 Hz
- If this clock could be locked for many years, it would lose .1 second per year
  - Not very good for atomic clocks, but better than the standard wristwatch

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Future Work

- Correct DAVLL drifting so that the system will lock for a longer period of time
- Characterize and optimize CPT