Optically Pumped Rubidium Atomic Clock
Final Presentation

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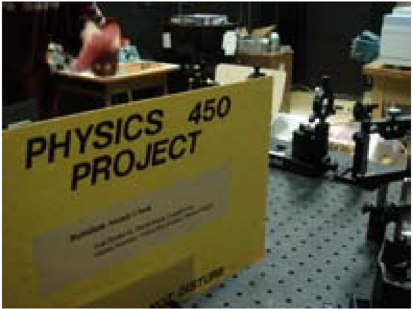
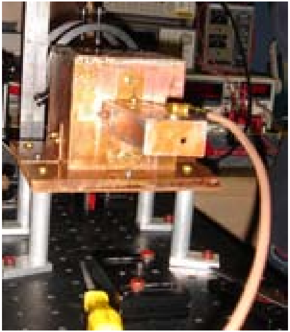
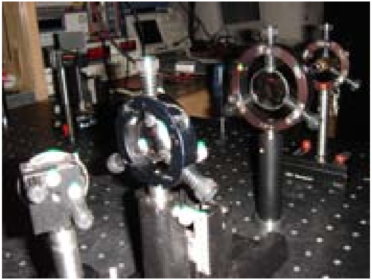


Outline

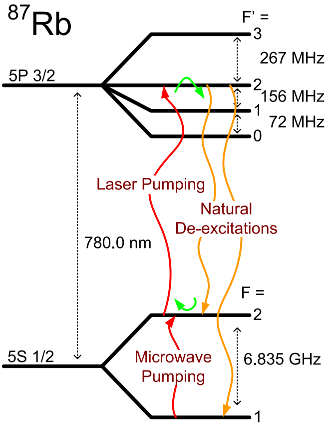


Objectives

- Design and construct a rubidium frequency standard / atomic clock
- Resolve hyperfine absorption spectrum for 780nm ^{87}Rb optical transitions
- Resolve sub-doppler double resonance peak for optical + 6.834Ghz hyperfine ground state transition
- Short term frequency stability: Verify that short term stability is superior to available quartz oscillators ($\approx$ 1 s in 30 years or 10^{-9})
- Long term stability: Use GPS timing to check for any long term drift or variation in output frequency ($\approx$ 1 s in 3000 years or 10^{-11})

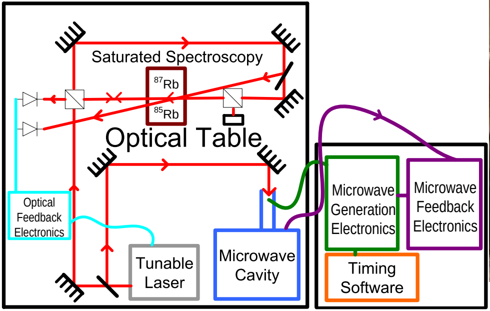


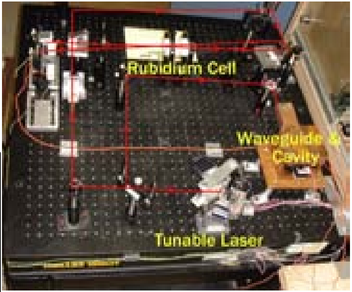
Rubidium Energy Levels



- A rubidium frequency standard is an oscillatory signal precisely tuned to the 6.835 Ghz
- The second is defined as the unit of time during which the signal from a similar Cesium transition has cycled 9.192631770×10^9 times
- In order to do this the $F = 2$ state must be optically pumped by a precisely tuned laser, overpopulating the $F = 1$ state
- A microwave signal will then excite the $F = 1 -> F = 2$ transition, completing the cyclic double resonance

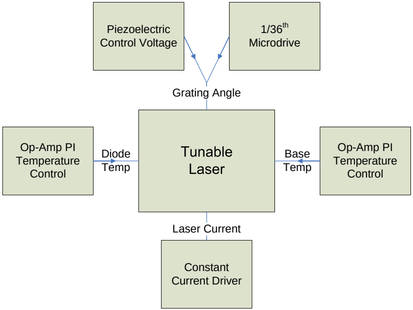
Overview

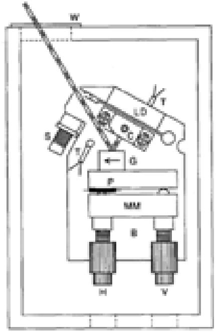




- The tunable laser provides the beam for the optical pumping and is controlled from the output signal of the saturated spectroscopy
- A chain of ICs and PCBs provide the microwave beam for the ground state transition and is controlled from the lock in amplifier

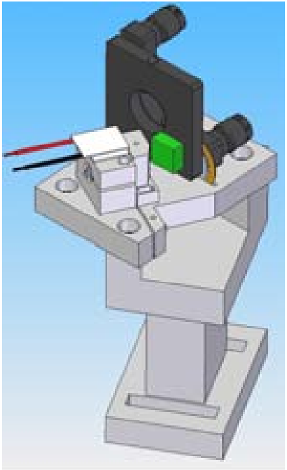
Littrow Diode Laser





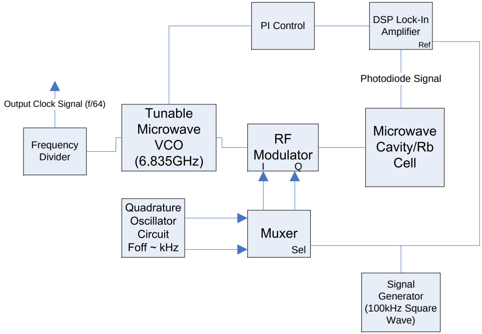
- A tunable diode laser was built in the extended cavity Littrow Configuration
- A diffraction grating provides both tunability and stabilization with a linewidth of $\approx$ 1 MHz (10^{-8} resolution)
- Various control systems were designed and implemented to give us this stability and control

Littrow Diode Laser



- Careful planning yielded a precise & deterministic device

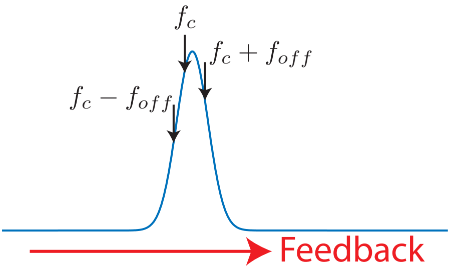
Microwave Synthesis



- Electronics design optimized to minimize number of high frequency components required.
- Frequency-division employed to produce manageable final output for counting/measurement

Microwave Feedback Loop

- Microwave signal from VCO will be modulated symmetrically about the center frequency
- It is the modulated signal that will be injected into the cavity
- Frequency modulation drives intensity fluctuations in photodiode
- We can phase-lock to these fluctuations using the modulation clock as a reference
- Intensity of phase-locked signal provides error signal for feedback control of VCO frequency

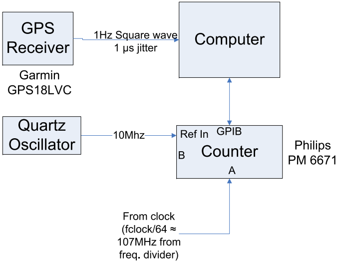


Measurement

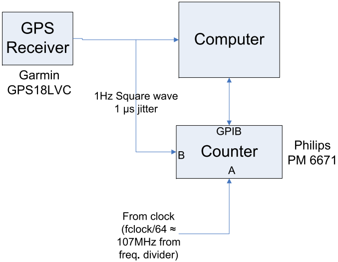
Figure: Testing GPS reception in outdoor mounting location.

- A GPS generates a 1 Hz pulse with a 1μs jitter on the rising edge
- The time at the beginning and end of a run would be recorded yielding a $\pm(\sqrt{2})1\mu s$ accuracy run length over arbitrary timescales
- GPS with Pulse Per Second timing output has been obtained and tested, cabled and mounted for consistant reception, providing the capability for long term stability testing of our clock signal or of other oscillators

Measurement - Instrumentation Setup

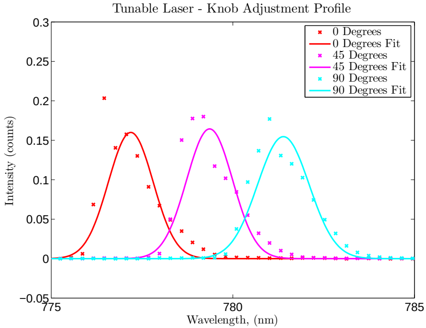


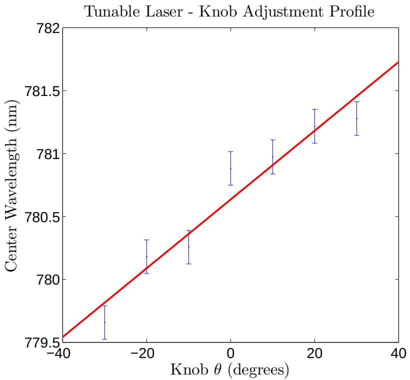
(a) Configuration for comparing short term stability.



(b) Configuration for comparing long term stability.

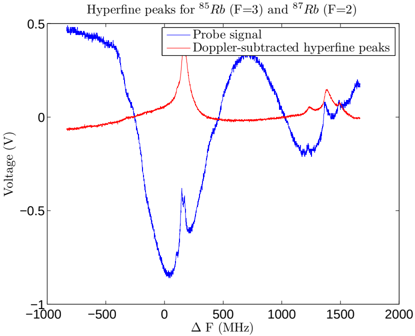
Littrow Diode Laser

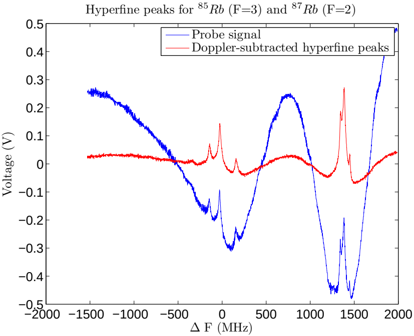




- Configuration utilizes a reflective diffraction grating for wavelength stabilization
- We have achieved a change in the lasing wavelength with the diffraction grating as shown

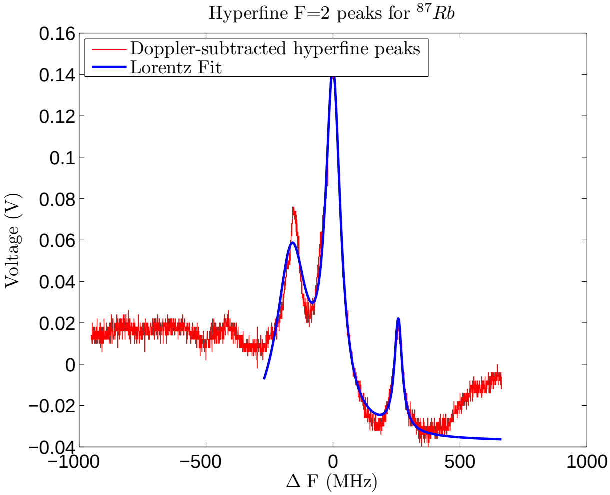
Rubidium Saturated Spectroscopy



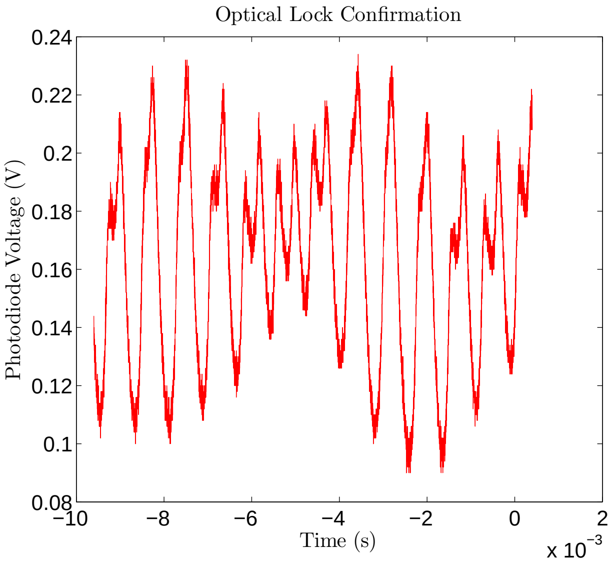


- The 6 allowed transitions for each rubidium isotope have been imaged using our saturated spectroscopy setup
- The frequency was swept by scanning the piezoelectric transducer

Rubidium F=2 peak - Hyperfine Resolution



Optical Lock



Safety Considerations

- Microwaves:
  - Low power consumption not a safety hazard
  - Low power output was not a safety hazard
- Rubidium:
  - The near vacuum conditions inside the cell ensure that even in the event of a rupture, there is not enough rubidium to cause severe acute health risks
  - The near-vacuum conditions inside the cell ensure that even in the event of a rupture, there will not be enough rubidium to cause severe acute health risks
- Laser:
  - Care has been taken to purchase appropriate goggles
  - Only two team members near the exposed beam at a time
  - Completed laser system placed in an opaque covering

Current Status & Conclusion

- The complete optical chain is performing far above expectations
- Side locking to the desired hyperfine peak has been achieved
- RF modulation has been proven in concept but implementation is still in progress
- Coupling of the RF signal is necessary for timing stability analysis
- The most difficult steps have been completed in the construction of an optically pumped atomic clock
- Our group has put forth a genuinely tremendous effort to get where we are
- We are happy with our current progress, however have not yet been able to obtain a stabilized clock signal
- Questions?