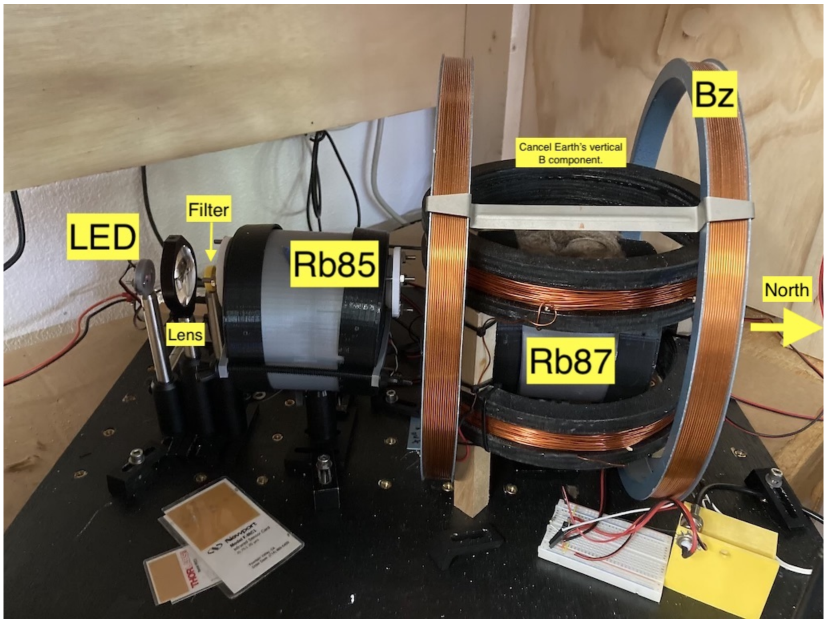
Rb atomic clock - Apparatus Summary

My latest (in-garage/Covid-year) effort



Vapor Cells

- Both Rb85 and 87 cells (25mm dia by 72mm length) are new and "heavy fill," meaning they have $\sim$ 10 mg of either Rb85 or Rb87 in each. The Rb can be seen as a silvery streak at room temperature, on the inside of the glass of the vapor cell.
- Rb87 has buffer gas of 15 Torr N2
- Rb85 has buffer of 75 Torr Ar.
- The Rb87 cell is in a thermal wrap/plastic container lined on the inside with four layers of mu-metal, minus holes to allow for light and microwave inputs. Holes for microwaves are large enough to minimize diffraction.
- The Rb85 cell has no magnetic field protection at all.
- Temperature controls on both cells to 0.1C. Currently set at 50C.
- Cells heating: Heaters are electric foil heaters. Cells sit in aluminum cradles, on top of a 2-cm aluminum blocks to maximize distance from the electric foil heaters and for some "thermal inertia." The heaters are clamped to the bottom of the blocks, and wrapped in mu-metal.
- we fear the Rb87 heater may be polluting the Rb87 cell's B-field environment. The heater is 2-cm from the cell and wrapped in mu-metal. The foil's zig-zag of out and return current paths are paired and next to each other, hopefully minimizing the generated B-field. Theoretically,

the B could be 0.2G near the cell, but we do not register anything on a Gauss meter when the heater is on vs. off. Resonance searches with heater off (for 5 min at a time and nearly constant cell temperature), do not show the resonance.

Magnetic fields

- The Rb87 cell is at the center of two Helmholtz coils, one along the optical path to establish B_z and another vertical, to cancel the vertical component of the Earth's magnetic field.
- About 60mA in one coil will set $B_z \sim 250$ mG.
- About 100mA in the other coil will cancel the ~ 0.4G vertical component of the Earth's field.
- Gaussmeter used regularly to check needed fields. Needed currents are consistent day-to-day.
- The optical path is oriented due north.

Light source

- Light source (two available):
  1. IR LED, which blankets 750-1000nm.
  2. A Hollow Cathode Lamp (HCL) that shows distinct 780 and 797 nm Rb lines.
- Either source is sent through a 750 nm+ bandpass filter on its way into the Rb85 cell.
- Light flow: LED (or lamp)→750nm+ bandpass filter→Rb85 cell→Rb87 cel→photodiode
- Thorlabs constant current driver on LED.
- Laboratory HV power supply on HCL ($\sim$ 300V at 10mA will drive the lamp). Most of what comes from the lamp are emission lines from the buffer gas Neon in the lamp. The two Rb lines are there, but weak.
- We're not sure if we're meeting the 100mW light threshold some papers cite. We'll track down a power meter and see. Anecdotally, the light emerging from the Rb87 cell is very weak from the lamp (barely visible on a IR card). The LED can produce as much light power as needed (and can be clearly visible on an IR card). The lowest current setting for the LED give about the same photodiode response as the lamp output.

Microwaves

- Microwaves delivered from SRS386 RF generator via a Pasternack resonant cavity, which is then attached to a horn.
- The horn is placed $\sim$ 60cm from the Rb87 cell (60 cm is "Rayleigh limit" for the 6.8GHz, allowing for linearly polarized electromagnetic wave to emerge from the Fresnel region near the horn aperture).

- Horn is oriented to have B-component parallel to the optical axis through the Rb87 cell. (Antenna stub in horn is perpendicular to optical path.)
- Microwave powers from -10dBm to 16 dBm are possible (we have a 3W microwave amplifier available too).
- Sweep is running on generator. Central frequency (f_0) is set, then sweep is $\Delta f = 1000$ Hz at 100Hz. All parameters are adjustable.
- $\Delta f = 1000$ Hz at 100 Hz is about $100,000$ Hz/s. It's best to stay below $600,000$ Hz/s. (There are of time-constants involved with optical pumping. Our teaching-lab on optical pumping pumps Zeeman split lines in about 16 ms, which relax in about the same amount of time.)
- We are a bit blind as far as the microwaves go. We do not have a power meter, receiver, or spectrum analyzer for this frequency at all. A diode in another horn from an educational kit does show a response to the microwave field however.

Detector

- IR Photodiode on exit face of Rb87 cell is amplified using trans-impedance, low-noise op-amp with gain of $\sim 1,000,000$.
- Signal of 750 nm+ light emerging from Rb87 cell is about 100mV with the lamp, and can go up to 2V with an LED at full power.
- Electrical signal from photodiode amplifier examined for noise on a spectrum analyzer looks clean other than 60Hz and 120 Hz (line) noise.

Lock-in amplifier

- We understand resonance dip will be small, maybe $\sim$ 100 nV reduction on $\sim$ 100 mV (Saxena) of overall response on the photodiode.
- Using a lock-in amplifier to look for resonance. Inputs are:
  1. Reference is 100Hz sync signal from microwave sweep.
  2. Signal is $\sim$ 100 mV of light from amplified photodiode embedded at exit aperture of Rb87 cell.
- Throughput test: If LED is externally modulated, the lock-in will instantly "lock on" to the modulated signal.

Resonance Search

- We understand the buffer gas in the Rb87 cell can shift the resonance by $\approx$ 500 Hz/Torr of buffer gas. For the 15 Torr of N2, we might see the resonance up +7500Hz relative to the theoretical 6.8 GHz.

- The Ar buffer gas in the Rb85 cell is supposed to broaden the Rb85 line that overlaps with the Rb87 F=2 line, and somewhat enhance the overlap with it (from Major, *The Quantum Beat*). Saxena recommends using N2 gas.
- The B_z can also shift the resonance, but by a smaller amount, maybe 10s-100s of Hz.
- Two methods for searching:
  1. LabView runs slow (10Hz/sec) microwave sweep of central frequency, f_0. Microwave generator sweeps $f_0 \pm 1000$Hz at 100Hz. LabView ramps f_0 through a large ($\pm 20,000$ Hz+) window around 6,834,682,610 while logging R (or X) from the lock-in. I've even let it run overnight sweeping in $\pm 500,000$ Hz window around f_0.
     - In such a scan, we expect to see the resonance profile when looking at R, or the error signal if looking at X. These scans typically come out flat. Any bump has never been reproducible.
  2. Put oscope in XY-mode. Microwave sweep sync input to X-axis on oscope. Lock-in "R" or "X" on oscope Y-axis. Look for resonance dip in real-time. All we see are broad fluctuations in the signal as a whole, with a period dictated by the lock-in's time constant setting.
- We are looking for peak (R from lock-in) $\sim$ 3000 Hz wide (1000 Hz sweep on low side + 600 Hz resonance width + 1000 Hz sweep on high side).