A PORTABLE RUBIDIUM FOUNTAIN[1]

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Abstract

We are developing a transportable laser-cooled rubidium (Rb) atomic fountain frequency standard. Over the last year, we have built the Ramsey cavity and rubidium source oven and are preparing to assemble the physics package. We have also made numerous refinements to the laser package, including transitioning to a new style of laser diode, vastly improving the optical phase-locked loops (OPLL), and improving the optical spatial mode to get more power out of the optical fibers. These refinements have enabled the laser cooling to collect many more atoms, which will improve the fountain's signal-to-noise ratio.

INTRODUCTION

For an overview of this project, we refer the reader to our previous reports **[1,2]**. Since last year's meeting, we have fabricated the microwave Ramsey cavity, launch tube, and rubidium oven such that the final physics package is nearly ready for assembly. We have refined our optical phase-locked loops for much-improved performance and a more compact package. The distributed feedback (DFB) laser diodes used in our system have exhibited unacceptably short lifetimes; thus, we have been replacing them with a new type of distributed Bragg reflector (DBR) laser diode, which we find to be much more reliable. Additionally, we refined the test vacuum chamber used to evaluate the performance of the optics package. These improvements have yielded an optical molasses with a much greater number of atoms, which improves the fountain's signal-to-noise ratio.

RAMSEY CAVITY

The design of our Rb cavity follows in the tradition of the cesium microwave cavities constructed by our group at NIST for the fountain primary frequency standards NIST-F1 and NIST-F2 **[3]**. In designing a microwave Ramsey cavity for a fountain frequency standard, there are always a number of decisions to be made on how to optimize for the specific fountain in question. For example, the number and location of the cavity feeds, the size of the cavity apertures, and the geometry of the cavity all affect the cavity's Q and distributed phase, which in turn affect the atoms.

Distributed cavity phase (DCP) shifts are a central concern in atomic fountain frequency standards claiming accuracy, and have been written about extensively **[4-8]**. They arise when the atoms experience phase variations in the microwave Ramsey cavity. Microwave cavity systematic biases are of less concern in a device to be used as a stable local oscillator, as long as the biases are stable in time. Fortunately, in a fountain, much of the longitudinal variations cancel out as the atoms make their return trip, and the shifts that do exist can be experimentally characterized due to their power dependence.

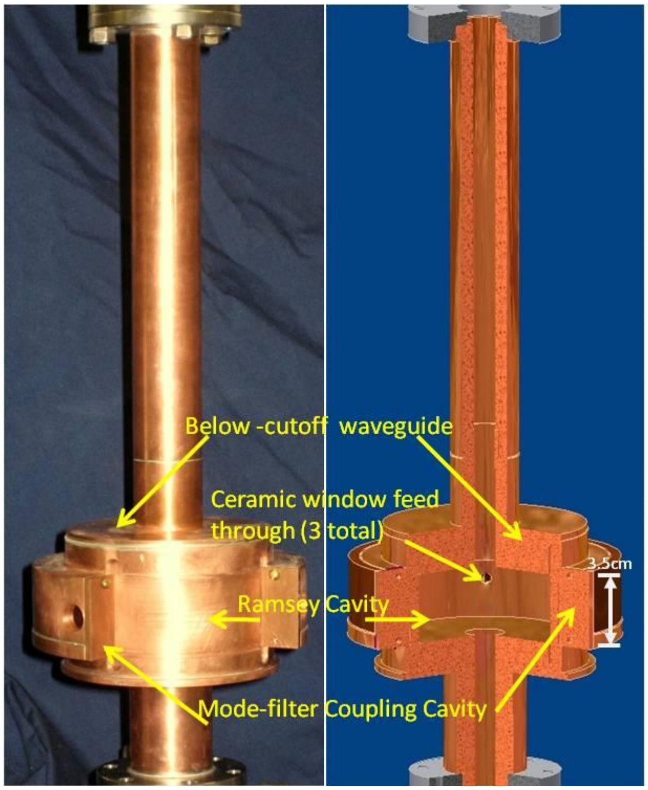

Figure1. On the left is a photo of the Ramsey cavity and on the right is a drawing with a cut-away view.

Our Ramsey cavity is constructed from OFHC copper and operates in the TE_{011} mode. The cavity is approximately 8 cm in diameter and 3.5 cm in height, and is brazed together to form a vacuum tight seal for the physics package (in the style of NIST F1 and F2 **[3]**). These dimensions were chosen so that the physics package could remain compact in the vertical dimension, and to reduce the DCP shifts. As a rule-of-thumb (as long as other modes are adequately suppressed), the phase deviation, $\delta\xi$, scales as

$$\delta\xi \propto \left(\frac{r_a}{r_c}\right)^{n_f} \cos(n_f \phi),$$

where r_a is the radius of the aperture, r_c is the radius of the cavity, n_f is the number of cavity feeds, and ϕ is the azimuthal coordinate in cylindrical coordinates **[3]**. This shows that it is better to have a wider cavity with multiple input feeds in order to reduce DCP shifts. We excite the cavity with a resonant mode-filter waveguide via three ceramic windows of approximately 0.5 cm in diameter. We wanted the simplicity of a single pair of input/output feeds to the waveguide while retaining more than two coupling points into the Ramsey cavity.

RUBIDIUM SOURCE

The source for the rubidium vapor in the cooling chamber presented an engineering challenge because our cooling chamber is all glass and lacks the access ports of a more traditional vacuum chamber. It consists of an ampoule of rubidium contained in a vacuum-tight copper tube that is wrapped with heat tape to form an oven. It is mounted to a small bellows that serves two purposes: first, it acts as a thermal break between the oven and the rest of the physics package, and second, it allows some flexibility when positioning the oven. The copper tube oven continues through the center of the bellows, and then turns 90 degrees to direct the vapor down into the cooling chamber. The pressure differential between the cooling and detection chambers is maintained by an extended graphite cylinder that limits the particle conductance between the two regions.

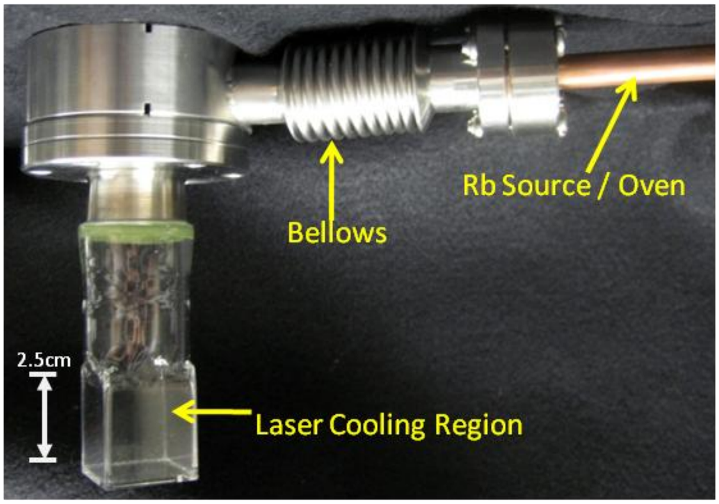

Figure 2. Picture of Rb source and laser cooling region.

LASER PHASE LOCK

In the last year. we have made a number of refinements to the optical phase-locked loops (OPLLs) in our laser system. These changes have improved performance from what was a rough frequency lock into a high-bandwidth phase lock with up to 70% of the laser power in the carrier.

The laser system is comprised of three slave lasers that are each independently locked to a single master laser. These three slave lasers provide all the light for the fountain except for the repump light. Currently, the repump laser is locked to its own saturated absorption spectroscopy module, though it would be straightforward to offset-lock it to the master laser, as the other slaves are (we may choose to do this in the future). As described in previous reports **[1,2]**, a small amount of power is picked off a slave laser and combined with a fraction of the master beam onto a fast photodiode detector. The radio-frequency beatnote between these two lasers is then amplified and compared to the output from a computer-controlled direct-digital-synthesizer (DDS) reference oscillator. This comparison is done by a digital phase-frequency detector chip which outputs an error signal that is then filtered and fed back to the slave laser.

One refinement carried out in the last year was a re-laying out of the printed circuit board (PCB) that held the phase/frequency detector and loop filter. By doing so, we significantly improved the circuit's high-speed performance. The PCB is now housed in a single-wide NIM module that is still mostly empty, thereby leaving room to install our home-built, computer-controlled DDS reference oscillator circuits into the same NIM modules.

Another critical improvement to our OPLL was to route the feedback signal directly back to the laser diode. Previously, we had sent the signal through a "fast modulation" input on the laser current driver module. Though we measured the transfer function through this fast input, and the response was flat up to 10 MHz, there was a group delay that severely compromised the loop response. Although routing the feedback signal directly back to the laser diode decreases the delay in the loop, it also increases the risk of damaging the laser. To mitigate these risks, we use a simple safety circuit that sends the signal first through a transistor. The transistor then siphons current away from the diode rather than adding current to it, making it inherently safer.

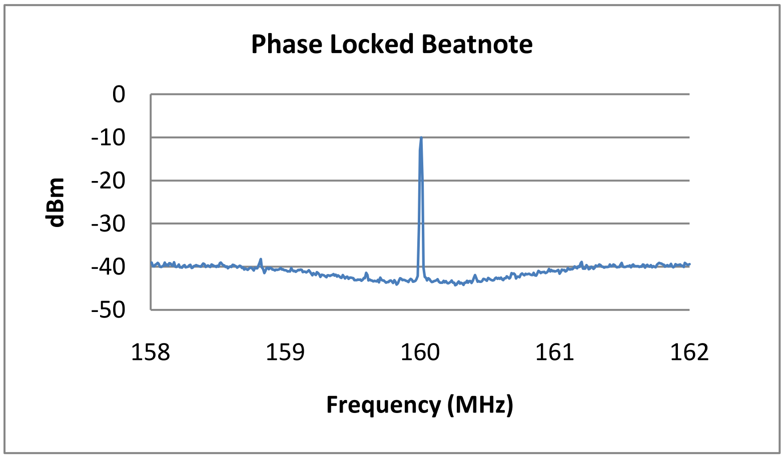

Figure 3. Beatnote between two phase-locked DBR lasers. The width of the beatnote is resolution limited (1 kHz).

CONCLUSION

We have designed and built a Ramsey cavity that meets our goals of simple and robust operation, compact dimensions, and reduced distributed cavity phase. Our rubidium source design has passed its initial tests, indicating that it can deliver ample Rb vapor into the laser cooling region of our physics package. With these pieces, our fountain physics package is ready to assemble. Our laser system has been significantly improved, as the OPLLs are now able to place 70% of the optical laser power into the phase-locked carrier. The optical molasses laser cooling in our mock physics package contains many more atoms now, which will improve the fountain's signal-to-noise ratio.

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