PROGRESS ON A PORTABLE RUBIDIUM FOUNTAIN FREQUENCY STANDARD*

P. D. Kunz, T. P. Heavner, and S. R. Jefferts
Time and Frequency Division
National Institute of Standards and Technology
325 Broadway, Boulder, CO 80305, USA
E-mail: ***kunzp@nist.gov, heavner@nist.gov, jefferts@nist.gov***

Abstract

We are developing a transportable laser-cooled rubidium (Rb) atomic fountain frequency standard. We have a complete optical package, and have recently shown cooled, launched, and detected atoms. Additionally, a new physics package has been designed and is currently under construction. Here we describe the recent progress made on this project, including refinements to our optical package and its evaluation, and our design choices for the physics package.

INTRODUCTION

Only a brief overview of this project will be given here, and we refer the reader to our previous reports **[1, 2]**. A "transportable" atomic fountain, in this instance, means a physics package measuring roughly 1 m^3 accompanied by a similarly sized electronics rack, such that the entire system would fit into a van or pickup truck. We will take advantage of the inherent frequency stability available in atomic fountains to develop the most stable type of transportable frequency reference ever created. A device such as this could be useful for comparing distant atomic standards where current time-transfer techniques are inadequate or impractical. It could also serve as an alternative to a hydrogen maser, and for independent measurements of the gravitational red shift.

OPTICAL PACKAGE

Our optical package has been described previously **[1, 2]**, but as a reminder its basic form is as follows. Semiconductor diode lasers provide all of the light used in our system. One laser is a master laser that is frequency-locked to a rubidium absorption line. The remaining lasers needed for cooling, launching, and detecting the atoms are then slaved (i.e., offset-locked) to the master laser. To achieve optimal cooling, launching, and detection, the frequencies of the various lasers must be precisely controlled. This is done in our system by locking the master-slave beat note to a programmable direct digital synthesis (DDS) frequency reference (see Figure 1).

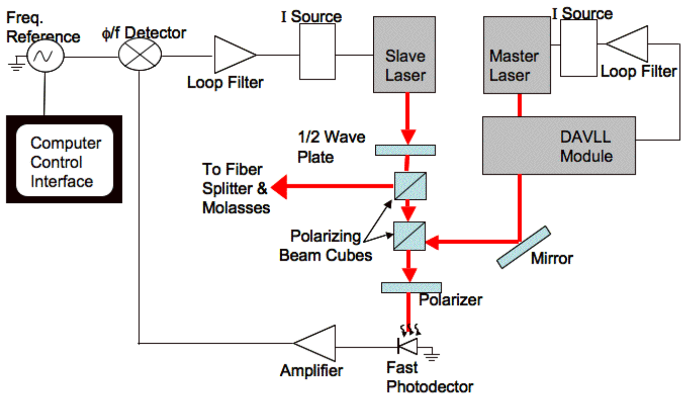

Figure 1. Diagram of offset-locking scheme.

A number of modifications have been implemented since our last report. Due to our recent decision to use a traditional (0,0,1) optical molasses geometry, rather than the (1,1,1), we now require one additional slave laser. In this configuration, there are five laser diodes (master, slave-horizontal, slave-up, slave-down, and repump). The horizontal slave laser also provides the detection light. This is done by use of an acousto-optic modulator (AOM). When the AOM's rf drive is off, the light passes through undeflected and is then fiber-coupled and delivered to the cooling region. Conversely, when the AOM is on, the first-order deflected beam is sent to a separate fiber that delivers it to the detection region. The AOM in this configuration also serves as a fast shutter. In addition, there is a mechanical shutter in front of the fiber for complete extinction. The repump light is combined with the horizontal cooling light by use of a polarizing beam splitter before both beams are fiber-coupled into a single fiber. There is one additional mechanical shutter through which both the up and down laser beams pass. These mechanical shutters are home built and designed for long lifetimes (greater then 10^8 cycles).

We have found that the original distributed feedback (DFB) laser diodes' lifetimes have proven inadequate (~10^2 hours). Recently a convenient alternative became available in a new distributed Bragg reflector (DBR) laser diode. This DBR diode not only promises a lifetime (~10^5 hours) that is more than adequate, but also has improved functionality over the previous diodes. This better functionality refers to a reduced linewidth (less than 1 MHz rather than ~3 MHz), and a reduction in demand for optical isolation (30 dB rather than 60 dB).

A new computer-controlled DDS frequency source has been developed to be used as the reference for the master-slave laser beat-note lock. This enables simple and flexible control over the frequencies of all the slave lasers. Controlled frequency sweeps and jumps are critical for post-cooling and launching the atoms, which in turn is critical for optimal fountain performance. Our DDS system consists of a programmable DDS chip, a microcontroller, and a graphical computer interface. Each DDS chip can hold four pre-programmed sweep patterns, which can then be triggered in real time via the computer interface. The microcontroller is used for its non-volatile flash memory, so that in the event of a power glitch, the DDS (which has only volatile RAM) will be automatically reprogrammed with the desired sweep profiles. If a new pattern is desired, the user simply reprograms the microcontroller (again using the computer GUI), which in turn programs the DDS chip (this takes roughly 1 minute).

Currently, we are evaluating the optical package on a vacuum chamber (see Figure 2) consisting of a cooling region and detection region (no microwave cavities). Incidentally, we are launching downward, since the available vacuum chamber was preconfigured that way. In Figure 3, we show the detected fluorescence signal from the launched rubidium atoms. Using the DDS reference system, we can vary the arrival time of the atoms by hundreds of milliseconds. This detection signal gives a direct metric by which we can optimize our optical package for improved signal-to-noise ratio in our final fountain system.

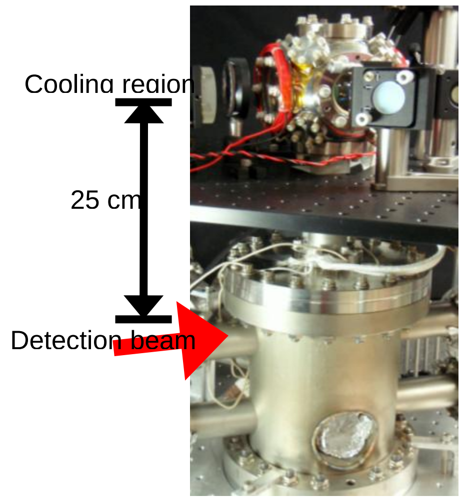

Figure 2. Experimental apparatus used to test the optical package.

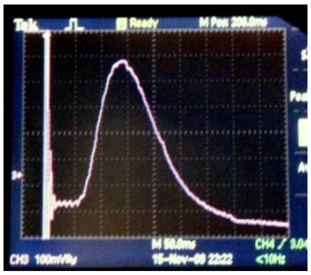

Figure 3. Fluorescence signal from launched atoms.

PHYSICS PACKAGE

In the design of our new physics package, currently under construction, we sought a compromise between maximum compactness and flexibility for evaluating a variety of fountain schemes. The design fulfills our requirement of transportability (it measures roughly 65 cm tall), yet allows for much freedom regarding methods of atomic cooling, state selection, and detection.

All atomic fountains share a few basic design parameters. They must implement laser cooling, state selection, a microwave cavity, a drift region, and a method for detection. Our design conforms to these standards, but with a few twists atypical of standard atomic fountains. First, our laser-cooling takes place in an all glass region measuring approximately 15 cm^3 (see Figure 4). Not only does this fulfill our requirement for compactness, but it also allows us to consider using a magneto-optical trap (MOT), which

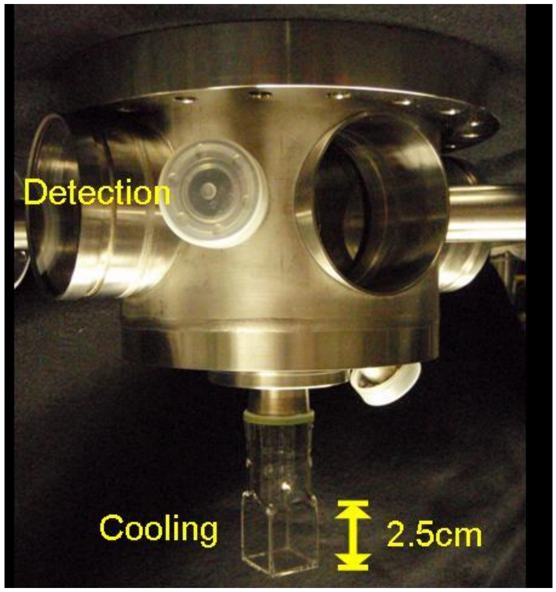

Figure 4. New cooling and detection chambers.

increases atom number. Most of the best fountains operating around the world use optical molasses rather than a MOT. One important reason for this is that the magnetic trapping fields used in a MOT can cause significant systematic shifts that are difficult to accurately characterize. Our small, all-glass cooling chamber means that the MOT's magnetic trapping coils can be much smaller and use much less current, thereby reducing their effect on the rest of the system. Furthermore, we have left ourselves the possibility of forgoing a separate cooling chamber altogether. Fountains generally form each cloud of cold atoms out of a background vapor that is maintained by an atomic sample repository in an oven. While the Rb partial pressure in the cooling region can be 10^{-9} to 10^{-8} torr (for fast loading times and large measured atom number), it is critical to minimize the leakage of this vapor into the detection region, where it would just increase measurement noise. Unfortunately having these separate regions adds measurement "dead time," because they are outside the Ramsey interrogation. We have included in our design the option for combining the cooling and detection regions into one, and loading an optical molasses from a directional cold atom source (such as a 2D MOT or LVIS **[3]**). This not only reduces the measurement dead time, but would also lead to a more compact package.

Our state selection scheme differs from the standard method employed by most atomic fountains. Often a fountain has two nominally identical microwave cavities where the lower one is used for state selection and the upper one for Ramsey interrogation. We avoid the extra space and measurement dead time consumed by the state selection cavity by designing a state selection cavity formed directly in the stainless steel vacuum flange of the detection region (see Figure 5). This choice of state selection cavity means that the atomic pumping transitions are not the usual $\Delta m_F = 0$ but rather $\Delta m_F = +/-1$. Traditionally, state selection is achieved in the following way. As the atoms enter the state selection cavity, their population is evenly distributed among all m_F magnetic sublevels; the cavity then induces a π-transition that transfers the $m_f = 0$ sublevel population to the adjacent hyperfine (F) level, leaving the rest of the atoms to be blown away by a resonant laser pulse. Alternatively, our scheme will optically pump the atoms into a stretched state of the lower hyperfine level ($F = 1$, $m_F = +1$); from there our compact state selection cavity induces a population transfer to the desired measurement state ($F = 2$, $m_F = 0$). In this way we also greatly increase our measured signal, because we get essentially all atoms into the measurement state.

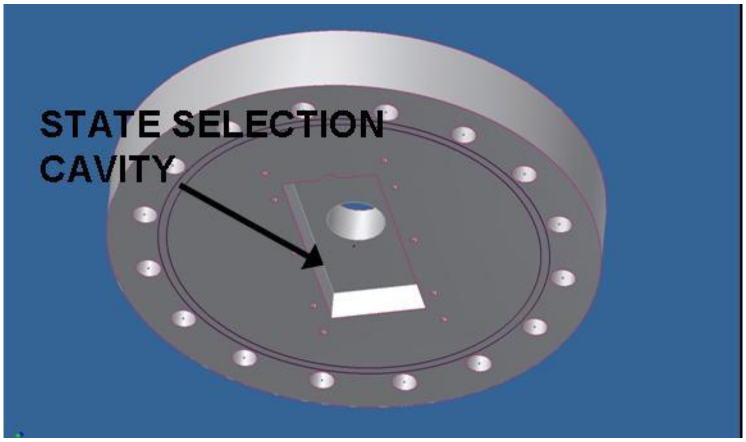

Figure 5. State selection cavity built into vacuum.

CONCLUSION

As described above, we have a complete and functioning fountain optical package. We will continue to optimize this package for improved sub-Doppler cooling and greater signal-to-noise ratio. Additionally, we plan to investigate options for further automating this system to improve the stability and ease user operation. In parallel, we will be assembling the new physics package and working towards bringing the two packages together.

REFERENCES

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[3] E. A. Donley, T. P. Heavner, and S. R. Jefferts., 2005, *"Optical Molasses Loaded From a Low-Velocity Intense Source of Atoms: An Atom Source for Improved Atomic Fountains,"* **IEEE Transactions on Instrumentation and Measurement, 54,** 1905-1910.