

# PRELIMINARY RESULTS FROM A MINIATURE LASER-COOLED CESIUM FOUNTAIN FREQUENCY STANDARD\*

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The Time and Frequency Division of the National Institute of Standards and Technology (NIST) is developing a miniature laser-cooled Cs-fountain frequency standard. We anticipate that this device will be useful as a transportable reference for comparison of standards at other laboratories. Additionally, it could be useful for measuring the gravitational clock shift at various locations. We discuss the objectives of this device, the features of the physics package and preliminary results.

## 1 Introduction

The miniaturization of a Cs fountain frequency standard is appealing for several reasons. A transportable device similar in concept to the PHARAO (Projet d'Horloge Atomique par Refroidissement d'Atomes en Orbite) clock [1] allows for the comparison of standards and calibrations at other laboratories and remote sites. Also, such a device could be used to measure the gravitational clock shift at various locations. While a small fountain cannot achieve the sub-Hz linewidths and ultimate accuracy of a primary standard such as NIST-F1, the compact geometry lends itself to achieving high stability. Considering the  $t^2$  dependence on toss height, a small atomic fountain using a  $\sim 15$  cm toss height still yields relatively long Ramsey times of  $\sim 0.4$  s. The shorter Ramsey time in conjunction with large apertures (1.4 cm) in the microwave cavities allows for a higher flux of Cs atoms through the clock as compared to NIST-F1. Assuming that  $\approx 10^8$  Cs atoms are collected in 300 ms with a temperature of 2  $\mu$ K, and a 0.3 s Ramsey time, we expect this device to achieve a stability of  $\sigma_y(\tau) \approx 2 \times 10^{-14} \tau^{-1/2}$ , provided there is a suitable local oscillator to support it.

## 2 Physics Package

The physics package for the miniature fountain has been described in detail elsewhere [2], and is shown without the C-field and magnetic shields in Fig. 1. It

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consists of a cold Cs source region (MOT and optical molasses), state-selection cavity, detection region, and Ramsey microwave cavity. The apparatus fits into a  $\sim 30\text{ cm} \times 30\text{ cm} \times 1\text{ m}$  package suitable for transportation. Presently, the laser system is on a separate optical table and light is delivered via optical fibers to the physics package.

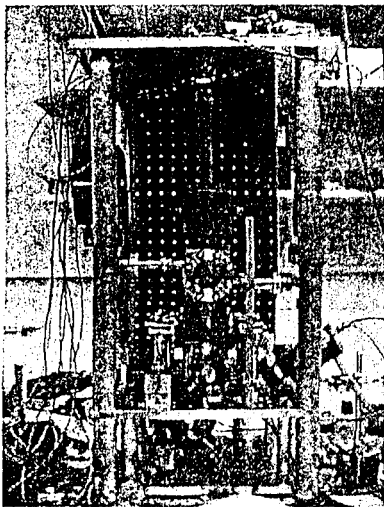


Figure 1. A photograph of the miniature fountain. Not shown are the C-field and magnetic shields.

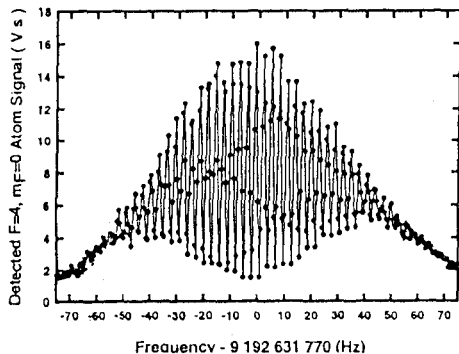


Figure 2. Ramsey fringes obtained with the miniature fountain.

The cold Cs source uses the (0,0,1) beam geometry and operates first as a MOT and then is switched into an optical molasses. Approximately  $10^8$  atoms are launched upwards by detuning the two vertical beams.

The state-selection cavity is a rectangular cavity operating in the  $TE_{104}$  mode. The apertures have a relatively large diameter of 1.50 cm, thus allowing for a large flux of atoms.

Directly above the state-selection cavity is the detection region, which is designed to measure both  $F=4$  and  $F=3$  atom signals in order to generate a normalized transition-probability signal.

The Ramsey microwave cavity and toss-tube assembly is constructed from high-purity oxygen-free copper. The cavity is cylindrical, operates in the  $TE_{011}$  mode, and has an unloaded  $Q$  of approximately 18,000. As with the state-selection cavity, the apertures in the Ramsey cavity have a large diameter of 1.4 cm. The cavity is fed with two loop antennas located opposite from each other in the mid-plane of the cavity.

The C-field bobbin has a winding pitch that produces a field of  $\approx 500\text{ nT/mA}$ . The magnetic shield package consists of three layers: one around the Ramsey cavity and toss tube, a second covering the first and extending down to shield the detection region, and a final shield enclosing the entire apparatus. For the preliminary results presented here, only the innermost shield was installed on the

system.

### 3 Preliminary Results

Presently, the detection system is configured to detect only atoms in the  $F=4$  state. Therefore, the data presented here are un-normalized and contain noise due to shot-to-shot variations in the atom number.

Figure 2 is a scan of the detected number of atoms in  $F=4$  versus the frequency of the microwave radiation in the Ramsey cavity, and shows Ramsey fringes and the underlying Rabi pedestal.

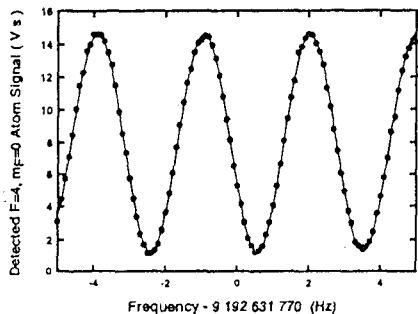


Figure 3. A narrow scan of the central Ramsey fringes. The offset is due to the relatively large C-field. The solid line is a fit to a sine wave.

The atom toss height above the center of the Ramsey cavity was 13.2 cm (40 cm above the source), resulting in a Ramsey time of 0.33 s and a Rabi time of  $1.2 \times 10^{-2}$  s, which is in good agreement with the measured fringe data. Each point in the scan is the average of two individual measurements. Figure 3 is a narrow scan about the central Ramsey fringes. Here each point is the average of 8 individual measurements, and the solid line is a fit of the data to a sine wave. The central fringe is offset by  $\approx 2$  Hz due to the relatively large C-field ( $\approx 7 \mu\text{T}$ )

applied during the measurements.

### 4 Acknowledgements

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### References

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