PROPOSED LASER-COOLED ^{87}RUBIDIUM LOCAL OSCILLATOR

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1 Introduction

A schematic diagram (not to scale) of the device is shown in Fig. 1. The basic idea of a laser-cooled beam-based atomic clock is not new and the device described here has many similarities to as well as significant differences from a device first described by Buell and Jaduszliwer [1]. The low-velocity intense-source [LVIS] of atoms is shown at the bottom. Atoms (^{87}Rb) are ejected from this source with a longitudinal velocity of about 15 m/s and an angular collimation of 25 mrad. This atomic beam is next deflected, state-selected and focused by a magnetic quadrupole lens. The $|F,m_f\rangle=|1,1\rangle$ atoms which are selected are transferred to the $|2,0\rangle$ level by the state-selection cavity. The beam of $|2,0\rangle$ atoms enters the 95 cm long Ramsey cavity where it is interrogated via square-wave phase modulation(SWPM). Finally the populations of the F=1 and F=2 levels are measured via optical fluorescence in the detection region.

2 Apparatus

The atomic source for this clock is based on a LVIS of Rb atoms [2]. The LVIS is basically a magneto-optic trap with an engineered "leak" of atoms; the resulting atomic beam is quite bright, with an achievable atomic flux of 10^{12} atoms/(sr-s) with an angular spread of 25 mrad. Approximately 1/3 of the atoms are available in the desired $|1,1\rangle$ state and the achievable atom shot noise limited performance is thus $1.1\times10^{-14}/\tau^{1/2}$. The atoms leaving the LVIS have a longitudinal velocity of about 15 m/s (FWHM~3 m/s). The atom beam is overlapped with an optical beam which must not be allowed into the Ramsey cavity as it would produce large uncontrolled shifts. Also atom loss at the far end of the Ramsey cavity is significant if the atom beam is not further focused. A magnetic lens which the atoms enter just after they exit the LVIS addresses these problems.

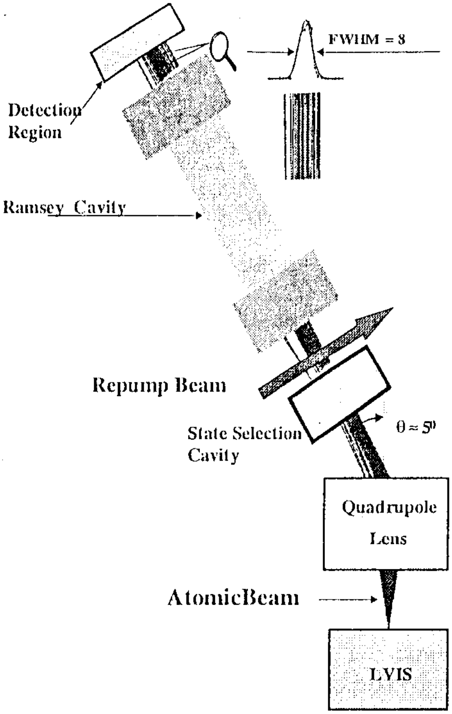

Figure 1 A schematic diagram of the apparatus (not to scale). Atoms leave the LVIS source and are focused and deflected in the quadrupole lens. The beam is state-selected with a microwave pulse and then traverses the Ramsey cavity. The atomic trajectories shown are modeled using the published [2] velocity distribution.

The magnetic quadrupole lens [3] (Fig. 1) has a focal length approximately equal to the distance from the lens to the center of the LVIS. The lens thus collimates the "point-like source" of atoms emerging from the LVIS. Actually the lens focuses only one of the three F=1 Zeeman levels; we have chosen the $|1,1\rangle$ level for the trajectory modeling shown here. The lens is situated so that the atom beam enters the quadrupole off axis, thus deflecting the atomic beam as well as collimating it. The deflection angle is of order 5°. The collimated atom beam emerging from the lens is therefore removed from the optical beam and state-selected, albeit not into the m=0 clock state. The $|1,1\rangle$ atom beam next enters a state-selection cavity that applies a π pulse at 6.835 GHz tuned to the $|1,1\rangle \Leftrightarrow |2,0\rangle$ magnetically sensitive transition. The atoms exiting the state-selection cavity next encounter a weak laser beam tuned to the F=1→F'=2 transition. This beam depopulates any atoms remaining in the F=1 manifold as well as quenching any coherence induced by the state-selection cavity.

The Ramsey cavity, shown in Fig. 2, consists of two TE_{011} cavities tuned to the 6.835 GHz hyperfine splitting and driven coherently but with independently selectable phase. This configuration has significant advantages for the operation of the clock as discussed in more detail in [4]. In particular, the use of SWPM allows the dead time associated with the modulation cycle to be of order the Rabi time (2 ms) instead of the 65 ms Ramsey time. This allows a cycle time of order 10ms instead of over 300 ms using traditional frequency modulation. The reduction in cycle time allows the use of a high quality quartz and while still achieving $\sim 10^{-14}$

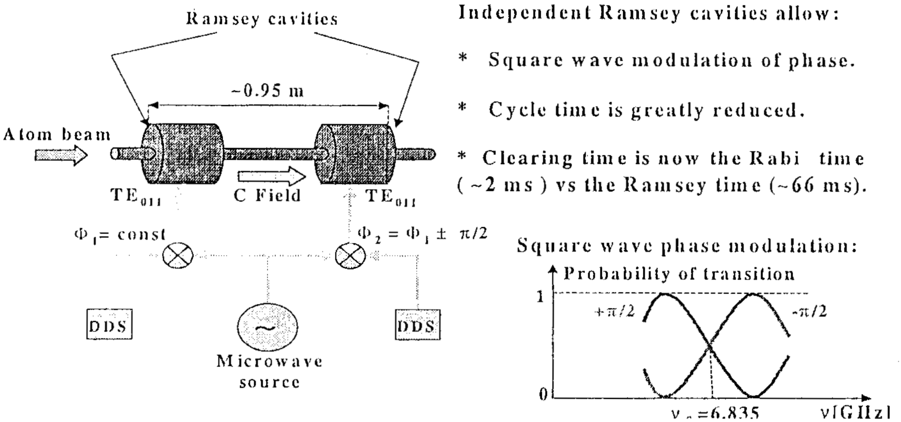

Figure 2 - Schematic diagram of the Ramsey cavity and the modulation scheme.

stabilities at 1 second. The cavities can have apertures of more than 1.5 cm without introducing significant instability.

The final step of detection uses two laser beams to detect the relative populations in the F=1 and 2 levels independently. This information is combined to give a transition probability. The measured probability in turn, steers the microwave frequency applied to the atoms. The resulting clock signal should have a stability in the low $10^{-14}\ \tau^{-1/2}$ range even when using quartz as a local oscillator. The long term stability is potentially in the low 10^{-16} range (or better) which, if achieved, makes this device a reasonable competitor to the hydrogen maser in terms of long term stability while having much better short term stability.

References

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