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THE EFFECT OF LASER LINE-NARROWING ON THE PERFORMANCE OF OPTICALLY PUMPED CESIUM ATOMIC BEAM FREQUENCY STANDARDS

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ABSTRACT

An experiment has been conducted to investigate the effect of laser line-narrowing on the performance of an optically pumped cesium beam frequency standard. A two laser scheme ($4 \rightarrow 4'\sigma$ for optical pumping and $4 \rightarrow 5'\pi$ for detection) was used and the lasers were either frequency locked to Cs saturated absorption features in an external cell or line-narrowed by optical feedback from an external Fabry-Perot cavity [1]. Relative to the frequency stabilization to the saturated absorption the line-narrowing on the detection laser produced a large improvement (+14dB) in the signal-to-noise ratio (S/N). However, line-narrowing on both pump and detector lasers was necessary to achieve beam shot noise limited performance. The S/N and line Q achieved in these experiments should result in a clock stability of $\sigma_y(\tau)=3\text{-}5\text{x}10^{-13}\tau^{-1/2}$ [2].

INTRODUCTION

The use of diode lasers for optical state preparation and detection in atomic beam frequency standards holds great promise for improvement in both the short term and long term performance of these standards. The potential for improved short term performance lies in the improved utilization of the atomic beam flux. A number of laboratories have begun experiments on optically pumped standards and the improved signal levels have been demonstrated. However, the potential signal-to-noise ratio (S/N) available has not previously been achieved when semiconductor lasers have been used as the optical source. This seems to be due to residual FM noise in the laser sources even when they are frequency stabilized to either atomic reference signals or optical cavities with servo systems of moderate speed. We have used an optical feedback scheme with an equivalent servo bandwidth of about a 200 MHz to reduce the laser operating linewidth. This in turn reduces the FM noise and the conversion of FM noise to AM noise by the Cs atoms.

EXPERIMENT

The experiments were conducted on the large optically pumped standard at the NRLM [3]. We used a two laser pumping scheme. The state preparation used the 4→4'σ transition while the detection used the 4→5'π transition. The optical power densities were 10's of mW/cm_2.

Two different laser frequency stabilization schemes were employed. A small portion of each lasers output was used to produce a saturated absorption spectrum in a room temperature cesium cell. The lasers had a small FM modulation at 2KHz and the saturated absorption signal was synchronously detected to produce a derivative type error signal for frequency reference. In the first lock scheme, this signal was used directly to control the laser center frequency by electronic feedback to the injection current. In the second case, the laser output linewidth was reduced by an optical feedback technique [1,4]. In this case, the saturated absorption signal was used to provide the long term frequency reference for the optical cavity. The laser output spectrum was not measured in these experiments but linewidths of much less than a MHz are to be expected [4].

RESULTS AND CONCLUSIONS

The results are given in table 1. The experiments labeled 1,2 and 3 are: 1) with broadband lasers locked to the saturated absorption, 2) with only the detector laser narrowed and 3) with both lasers narrowed. The measurements were all made in a static way with no modulation on the microwave radiation. The signal levels are given in arbitrary units and represent the difference between the detected signal level with the microwave radiation tuned to the center of the Ramsey resonance and well outside the hyperfine spectrum. The noise is measured at the peak of the Ramsey resonance in a 1Hz bandwidth centered at 75Hz.

Table 1

Experiment	1	2	3
Signal level	1	1.53	1.40
S/N	450	2300	6500

The increased signal produced by narrowing the detection laser was the result of increased power spectral density on the cycling transition while the increased S/N was the result of the reduced FM noise on the laser. The slight loss of signal when the pump laser was narrowed may have resulted from an offset in the cavity frequency reference servo and a corresponding reduction in the pumping efficiency. In-spite-of this error, the detected S/N was further improved. The interpretation of this would seem to be that in the absence of line-narrowing, some laser frequency excursions are large enough and last long enough that some atoms pass the pumping region without interacting with the laser. This flux of unpumped atoms, while small, can contribute a detectable background signal which contains the added noise. When the pump laser was line-narrowed, even though it was locked slightly off resonance and some flux of atoms passed unpumped, the background they produced at the detector contained no added noise. The total background level which was a composite of scattered lights, fluorescence from background cesium atoms and fluorescence from unpumped atoms in the beam was equal in magnitude to the Ramsey signal.

In the case with both lasers line-narrowed, the S/N ratio on the detected signal was essentially beam shot noise limited. When combined with the Ramsey resonance line Q we observed (1×10^8) and a standard clock servo analysis [4], this S/N should result in a clock stability of $\sigma_y(\tau) = 3\text{-}5 \times 10^{-13}\ \tau^{-1/2}$ depending on the type of modulation scheme chosen. This demonstrates that the full potential for short term statistics offered by optically pumped cesium is available if lasers with proper noise performance are used.

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