COMPACT CESIUM BEAM FREQUENCY STANDARD : IMPROVEMENTS OF THE FREQUENCY STABILITY TOWARDS THE $10^{-12}\ \tau^{-1/2}$ LEVEL

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ABSTRACT

We operated the compact (2dm^3 in volume) optically pumped cesium beam resonator Cs4 with a new optical set-up : the clock signal detection is achieved by means of a cycling transition. The signal-to-noise ratio in a 1 Hz bandwidth is 28500, obtained with a low atomic flux corresponding to a cesium consumption of 0.5 g per year. The measured frequency stability is now equal to $1.5\ 10^{-12}\ \tau^{-1/2}$ for sampling times varying from 1 to 10^4 s. Cs4 meets the frequency stability and lifetime requirements necessary to next space navigation systems.

Key words : Cs beam clock. Frequency stability. Optical pumping.

1. INTRODUCTION

The optically pumped cesium beam clock Cs4 designed with a compact resonator 2 dm^3 in volume (Ref. 1) was operated with a basic optical configuration which uses the same optical frequency for pumping and detection purposes. In this configuration, the laser source was a commercial DBR laser at 852 nm tuned to the F=3→F=3' transition of the Cs D2 line and σ polarized . A good short and medium term frequency stability was measured at low atomic flux, namely $1.6\ 10^{10}$ atoms/s in the detection region. We obtained : $\sigma_y(\tau) = 4.10^{-12}\ \tau^{-1/2}$ where τ, the averaging time, is in the range 1 second to 2 days (Refs2, 3). Moreover the clock accuracy was determined, equal to $4\ 10^{-13}$.

Recent requirements for navigation applications lead us to demonstrate that the short and medium term frequency stability of Cs4 can be improved to the level 1 to $2.10^{-12}\ \tau^{-1/2}$. It is well known that the short term frequency stability is related to the signal to noise ratio in the detected clock signal (Ref. 4). In the above mentioned optical scheme, it was equal to 10 000 in a 1 Hz bandwidth, limited by the additive detector noise. The way of increasing this S/N ratio is to detect the clock signal with a so-called cycling transition which gives high fluorescence photon yields.

This is why we implemented a new optical set-up delivering the two optical frequencies required for pumping and detection purposes. In the next sections we first briefly recall the features of Cs4 and describe the new optical configuration. Then we give the results concerning the frequency stability of Cs4.

2. DESCRIPTION OF THE APPARATUS

2.1 General description

A detailed description of the frequency standard Cs4 can be found in previous papers (Refs 1, 3). Let us recall its main features. The microwave interaction is achieved in a Ramsey cavity which is 18 cm long. The microwave fields are phase opposite in the two arms of the cavity, leading to a minimum probability at resonance. The Ramsey resonance line is 660 Hz wide. The cesium oven is heated at 90°C and the resulting cesium consumption is 0.5 g per year. The frequency of the microwave signal is continuously square wave modulated. The modulation depth ω_m and the Rabi angular frequency b are set at values which optimize the short term frequency stability and cancel the cavity pulling effect (Ref. 5).

2.2 Optical set-up

The 4→4 σ polarized transition of the Cs D2 line, which gives the best population difference between the two levels of the clock transition, is used for optical pumping. Detection is performed with the σ polarized 4→5 cycling transition. The use of this transition offers two advantages : a velocity distribution in the atomic beam weighted by 1/v (Ref. 4) and a high photon fluorescence yield β which depends on the laser intensity and on the laser linewidth. Typical values β are 50 to 70 photons per atom, to be compared to 4 photons per atom in the case of the 3→3 σ transition. It then results a narrower clock signal and an enhanced signal amplitude.

In order to significantly increase the clock S/N ratio, we need to carefully prepare the cesium atoms. A small proportion of unpumped atoms increases the fluctuations of the fluorescence signal in the detection region. This excess noise linked to the frequency noise of the pumping laser limits the S/N ratio. Consequently the signal detection with a cycling transition requires lasers with good spectral purity. Thus we use a single extended cavity laser (ECL) locked to 4-5 transition of the Cs D2 line by means of the saturated absorption spectrum of a Cs cell. The laser linewidth is about 500 kHz. The pumping beam is obtained by shifting by 250 MHz a fraction of the laser beam through an acousto-optic modulator as shown in fig. 1. The laser beam intensities are respectively about 15 mW/cm^2 and 8 mW/cm^2 in the pumping and the detection zones.

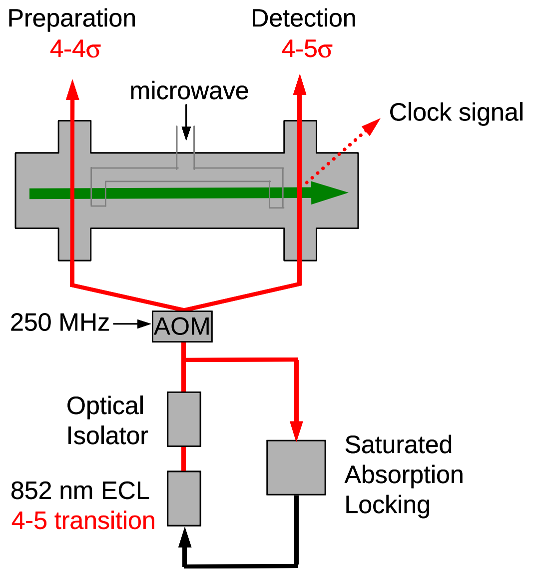

Figure 1 : Sketch of the optical set-up.

3. RESULTS

Figure 2 shows the clock signal obtained with this optical configuration. The S/N ratio in a 1 Hz bandwith is 28500.

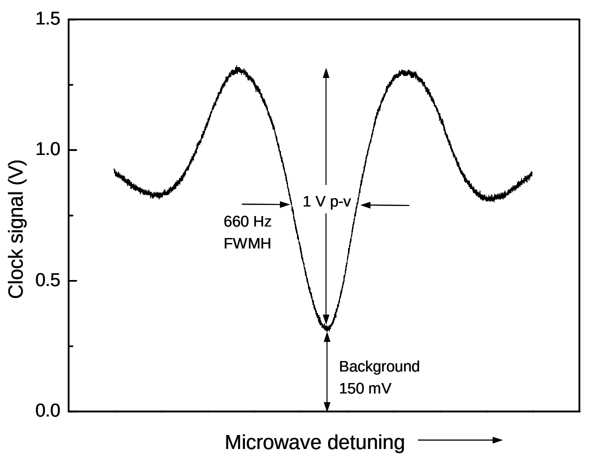

Figure 2 : Clock signal features.

The square root of the overlapping Allan variance is reported in fig. 3 with a Hydrogen maser as a reference. For sampling times of up to 10^4 seconds, the frequency stability shows the expected behavior of a white noise process. The measured data fit the line $\sigma_y(\tau) = 1.5\ 10^{-12}\ \tau^{-1/2}$. The flicker floor is not reached yet. The measured frequency stability agrees very well with the measurements made in the basic configuration where $\sigma_y(\tau)$ was equal to $4\ 10^{-12}\ \tau^{-1/2}$ whereas the S/N ratio was equal to 10000.

Further investigations will be devoted to point out the influence of the laser linewidth on $\sigma_y(\tau)$ through the use of commercial laser diodes with linewidths of about 1 MHz. Then we will deal with the long term frequency stability.

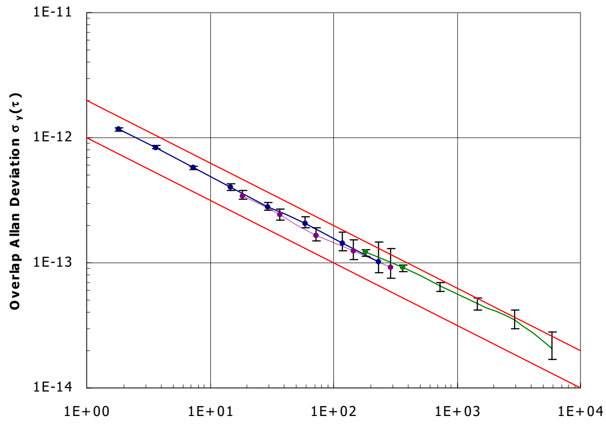

Figure 3 : Frequency stability of Cs4 measured against the H maser.

4. CONCLUSION

We have achieved the optical detection of the microwave resonance in the compact optically pumped cesium beam frequency standard Cs4 by means of a cycling transition. The laser used is an external cavity laser with a 500 kHz linewidth. We have demonstrated a significant improvement in the frequency stability of Cs4 hich is now $1.5\ 10^{-12}\ \tau^{-1/2}$ in the range 1 to 10000 s. It is worth noting that the atomic flux remains low.

These frequency performances allow us to consider Cs4 as a good candidate in the future space navigation systems.

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