FIRST COMMERCIAL PROTOTYPE OF AN OPTICALLY PUMPED CESIUM-BEAM FREQUENCY STANDARD

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Abstract

Tekelec has developed the first commercial prototype of an Optically Pumped Cesium-Beam Frequency Standard with the scientific support of the Laboratoire de l'Horloge Atomique (LHA) and the financial support of the French Military Administration (DGA). This work is based on years of experience of the LHA on cesium atomic clocks, especially on short atomic clocks and on the experience of Tekelec in time and frequency for systems (timekeeping, time distribution, synchronization, etc.) and components (quartz oscillators, rubidium atomic clocks, etc.). The first prototype is under characterization and the first results are presented in this paper.

INTRODUCTION

The huge growth of synchronization and positioning requirements for military, civilian, or space applications will rapidly increase the need for ever more accurate and cheaper frequency standards. We believe that the optically pumped cesium-beam frequency standard is a good candidate for these applications.

The optical pumping technology has improved widely the performances of laboratory clocks and is used in the best National Primary Atomic Clocks (LPTF[1], NIST[2]) replacing the magnetic deflection technology.

The Laboratoire de l'Horloge Atomique (LHA) has demonstrated[3,4] the ability of this technology to improve short system performance and, therefore, is of great interest for industrial applications.

Furthermore, the greater simplicity of this technology will lead to lower price.

PRINCIPLE OF OPERATION OF AN ATOMIC CLOCK

The scheme of Figure 1 represents the general operation diagram used in an atomic clock to stabilize the 10 MHz signal generated by a quartz crystal oscillator (OCXO) with the atomic resonator using a synchronous detection. The heart of such a clock is the cesium-beam resonator. The operation is based on the population difference between the two hyperfine levels of the ground state of the cesium-133 atom on which the definition of the second is based (Figure 2). The operation principle of a resonator is based on three main parts described Figure 3:

- The atomic preparation realizes the population inversion. The two hyperfine levels populations are naturally equivalent; the preparation eliminates one population (in the case of magnetic field technology) or realizes an optical pumping of the atoms to one hyperfine level (optical pumping technology). After preparation all the beam atoms are located on one level (F=4).
- The microwave interaction is realized by a microwave cavity; basically if the frequency is exactly tuned to the transition between the two hyperfine levels, there is a stimulated recombination. So the second hyperfine level is populated again (F=3).
- The clock signal detection analyzes the population of this level by a hot wire detector (magnetic deflection) or by the fluorescence given by optical pumping.

DESCRIPTION OF THE TEKELEC RESONATOR

The Tekelec cesium-beam resonator is described Figure 4. In the high vacuum conditions maintained by an ion pump, a cesium oven generates a very low divergence thermal cesium beam. This beam is shaped by several graphite diaphragms. The atomic preparation and signal detection are obtained by optical pumping using the same laser diode. The fluorescence signal in the preparation area is used to slave the laser diode frequency to the 3-3 transition of the D2 line ($6^2S_{1/2} \rightarrow 6^2P_{3/2}$) of the cesium frequency diagram (Figure 2). A Ramsey microwave cavity excited at 9.192631 GHz by a coaxial antenna is used for RF interaction. It is magnetically shielded and a low and very uniform static C-field is applied. In the detection area, the fluorescence signal is used as the clock signal. A second magnetic shield protects the optical areas and the cavity.

MAIN ADVANTAGES OF THE TECHNOLOGIES USED

The main advantages of the optical pumping compared to using a magnetic field are:

- the atomic preparation is complete, increasing the signal-to-noise ratio,
- all the atoms participate in the clock signal (twice as much as with magnetic deflection), allowing a lower cesium consumption,
- there is no strong magnetic field near the microwave cavity,
- the Rabi-Ramsey spectrum is very symmetric, increasing the accuracy and allowing a lower C-field, which decreases the magnetic sensitivity of the clock,
- the cesium speed distribution is well known, increasing the accuracy,
- there is no hot wire detector, which is very fragile, and limits the lifetime of the resonator,
- the technology is much simpler (without deflection), which will lead to lower cost.

Furthermore, we use an electric coupling and a cavity geometry giving an odd number of longitudinal modes, and then a phase difference of 180° between the two oscillatory fields that the atoms experience in succession. The LHA[5] has demonstrated that this configuration improves the frequency stability.

MAIN CHARACTERISTICS OF THE TEKELEC CLOCK

The aim of Tekelec is to produce a state-of-the-art cesium-beam frequency standard for an attractive price. The accuracy will be better than $1 \cdot 10^{-12}$. The stability in time and frequency domains are given Figures 5 and 6. The stability planned is given by $\sigma_y(\tau) = 6.3 \cdot 10^{-12}\tau^{-1/2}$ between 2 and 400,000 seconds, with a flicker floor at $1 \cdot 10^{-14}$. As far as we know, these characteristics are the best values published for a commercial standard.

FIRST RESULTS

A prototype has been realized and is under characterization. The full numerical electronics have been tested and their phase noise fulfills the planned frequency domain characteristics. The Rabi-Ramsey resonance fringes have been obtained and are represented in Figure 7. The difference between two fringes is 42 kHz, corresponding to a C-field of 6 μT. These fringes present a minimum at the center (black fringe) which is characteristic of an electric coupling of the cavity (antenna). The spectrum is very symmetric, as expected. The central line, which is used as clock signal, is given in Figure 8. The linewidth (FWHM) of the central line is 600 Hz, which is the theoretical value for the cavity length and the atoms' speed. This value, combined with a signal-to-noise ratio of 10,000, will lead to a stability better than the planned stability. The LHA[6], in a similar size resonator, has obtained $\sigma_y(\tau) = 2 \cdot 10^{-12}\tau^{-1/2}$, with a flicker floor of $2 \cdot 10^{-14}$, a line width of 660 Hz, and an old and nonoptimized analog electronic system. So we believe that, with our resonator and our modern fully automatic and optimized digital electronic system we will fulfill, and even improve, the expected performance of the clock.

CONCLUSION

Tekelec has developed a prototype of an optically pumped cesium beam frequency standard with the scientific support of the LHA. The first results show that the goal of the Tekelec clock, to be the state of the art of commercial frequency standards, is reachable. This belief is confirmed by the very good results obtained by the LHA in a equivalent lab prototype and with an old-fashioned electronic system. This prototype will be industrialized in two versions: one in the conventional 19", 3U size and one compact version for military applications.

REFERENCES

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[6] B. Boussert 1996, thesis, Université de Paris, XI Orsay.

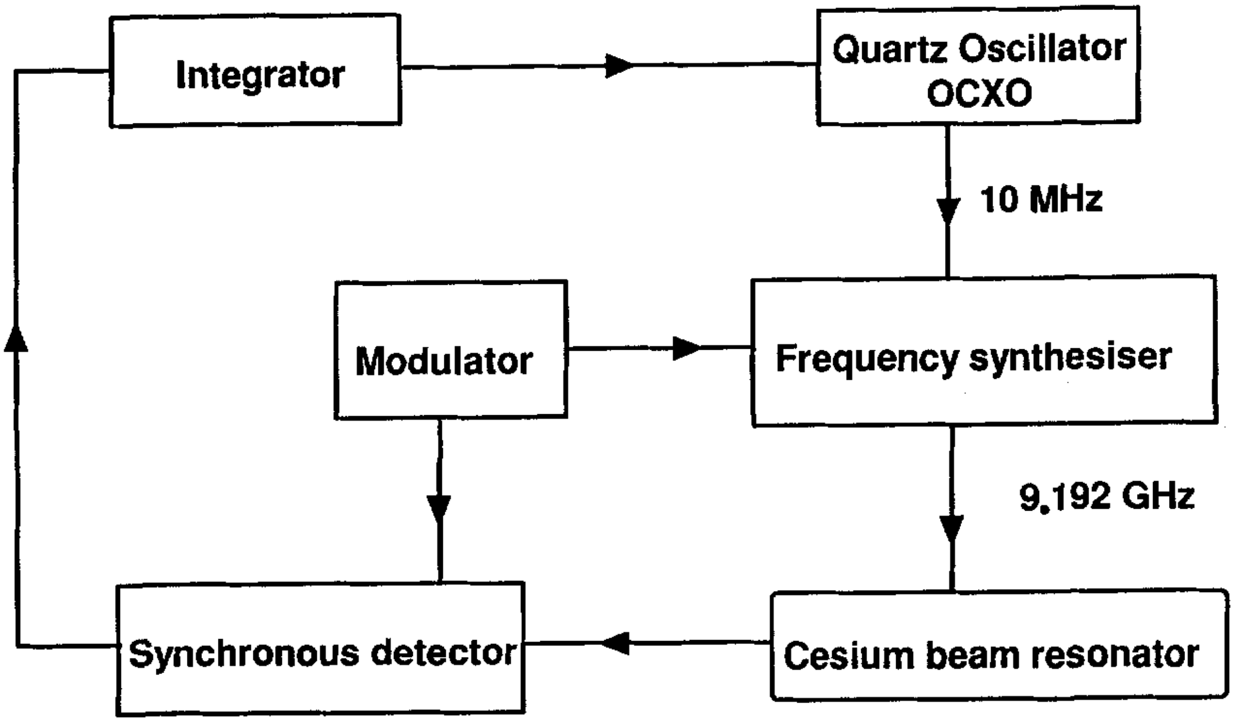

Figure 1 : Block diagram of the operation of an atomic clock

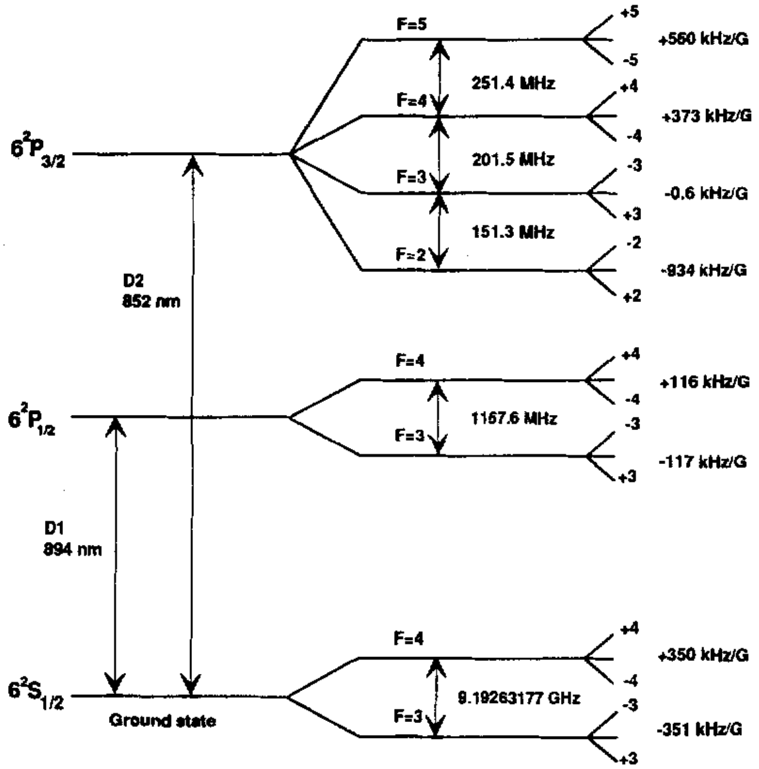

Figure 2 : Energy levels of the cesium 133 atom

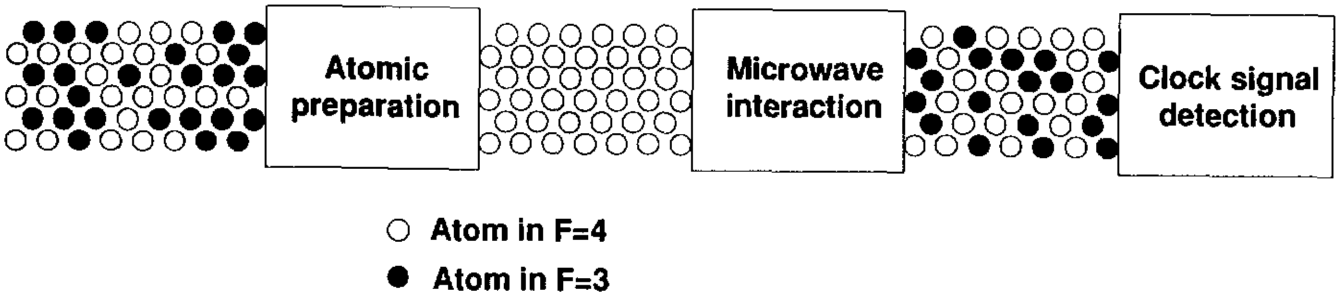

Figure 3 : Atomic resonator principle

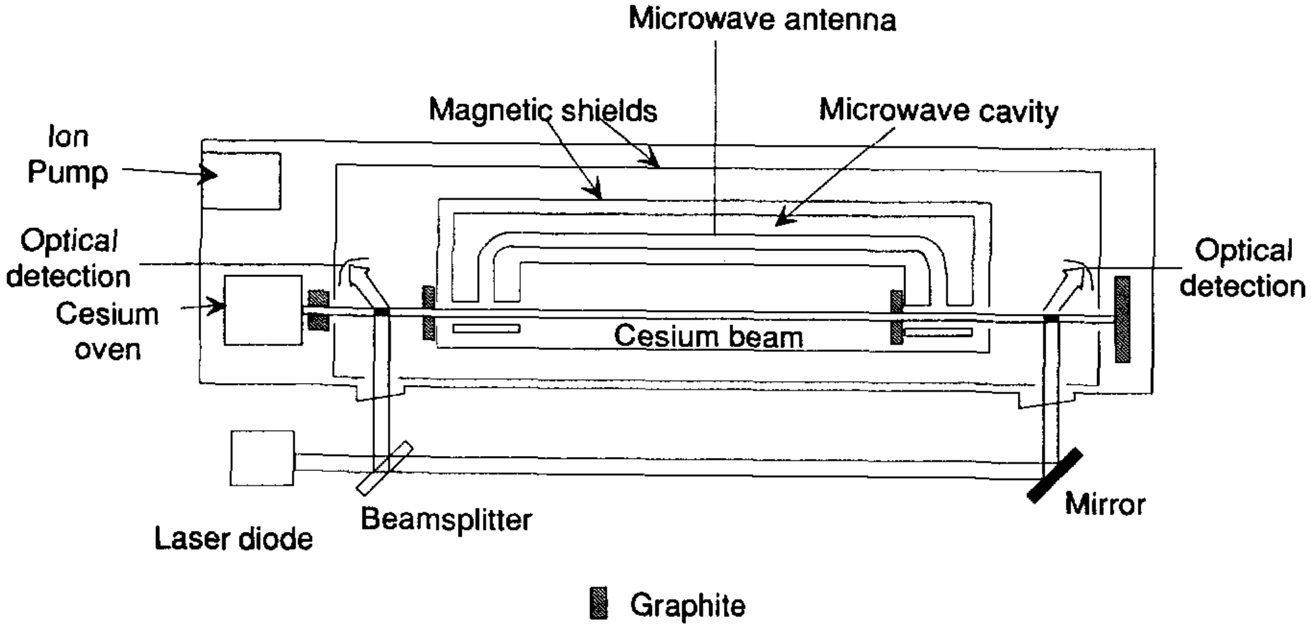

Figure 4 : Optically pumped cesium beam resonator

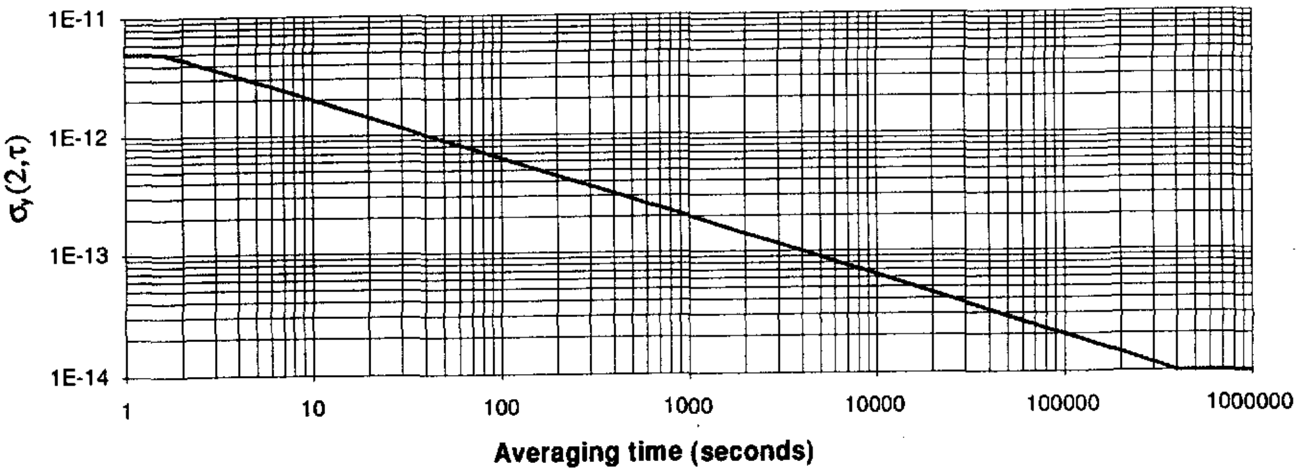

Figure 5 : Time domain stability (Allan deviation)

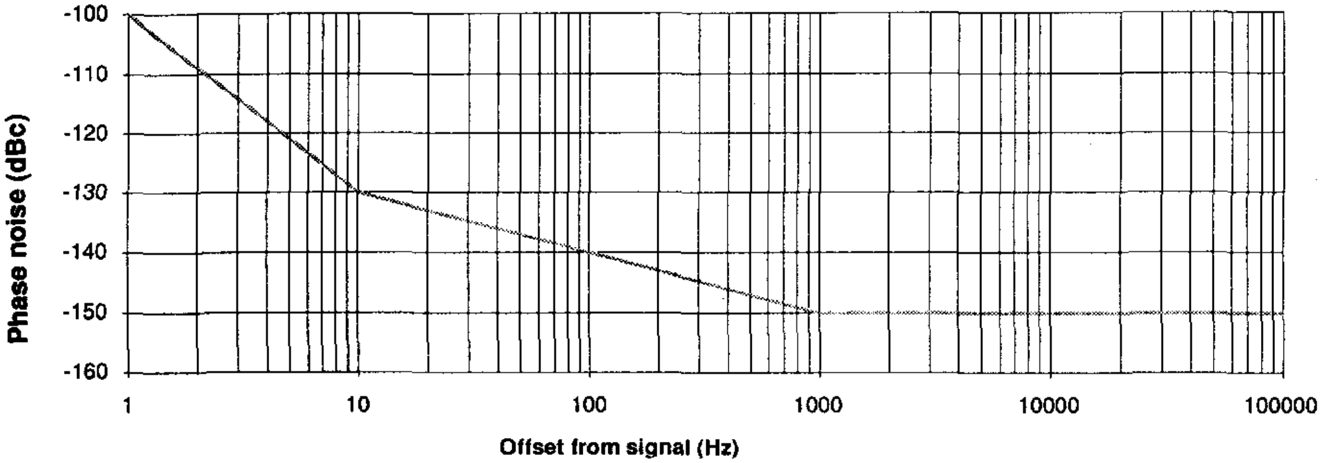

Figure 6 : Frequency domain stability

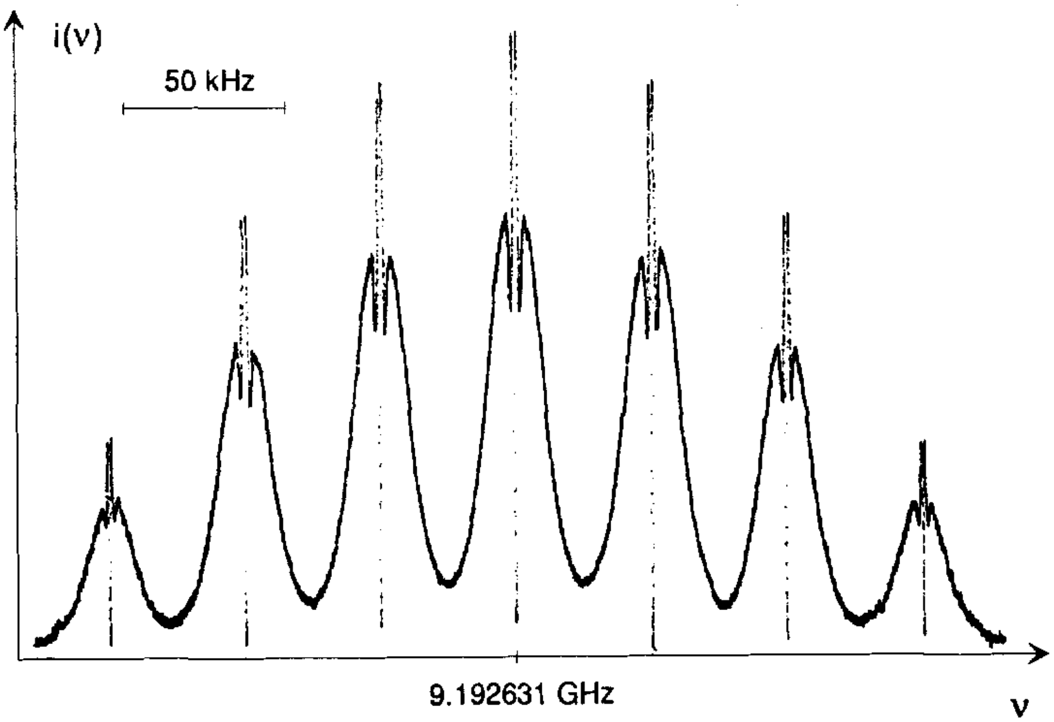

Figure 7 :Rabi-Ramsey fringes

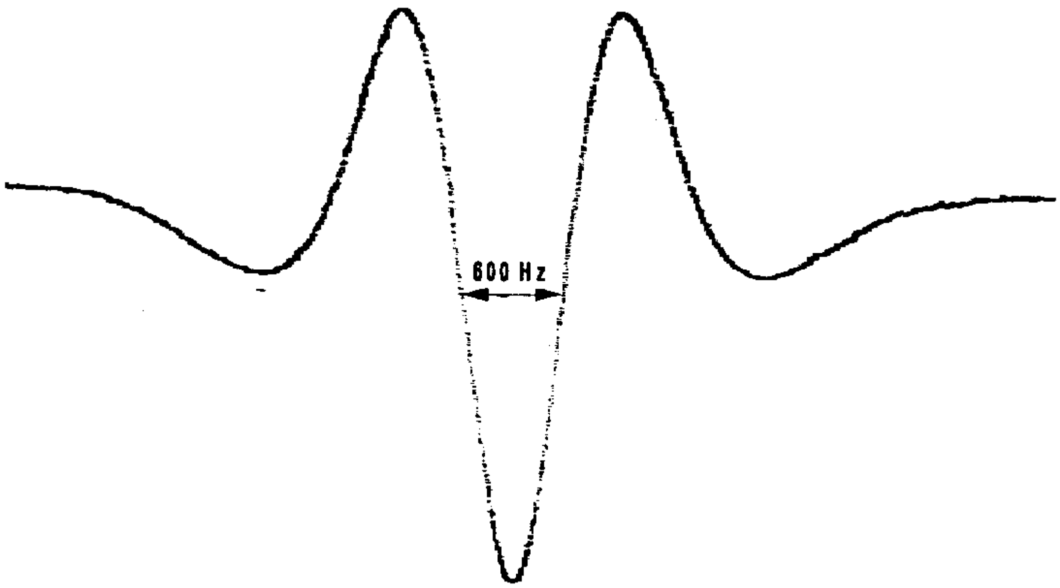

Figure 8 :Central line of the Rabi-Ramsey fringes