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INTER-LABORATORY TIME AND FREQUENCY TRANSFER BY OPTICAL FIBER

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Abstract – All the available frequencies in the three Time and Frequency laboratories of Besançon (an Hydrogen Maser at the LCEP, cryogenic resonator oscillators at the LPMO and atomic clock at the LAOB) constitute the state of the art in term of time and frequency references. An optical interlaboratory link of metrological quality makes possible to share these references of frequency between the various sites. The aim of this paper is thus to characterize the optical link stability and to develop a system to correct the phase fluctuations due to optical fibers. We want to be able to transfer a signal stability of relative frequency of $2 \cdot 10^{-15}$ for a few weeks.

Keywords - Optical link, 100MHz, Cesium, Hydrogen Maser, Short term frequency stability

I. INTRODUCTION

In Besançon, three laboratories are leading complementary researches in Frequency and Time metrology. Each laboratory owns its standards. For short term frequency stability, ultra high stability signals are now available at the LPMO from cryogenic resonator - oscillator in X band.

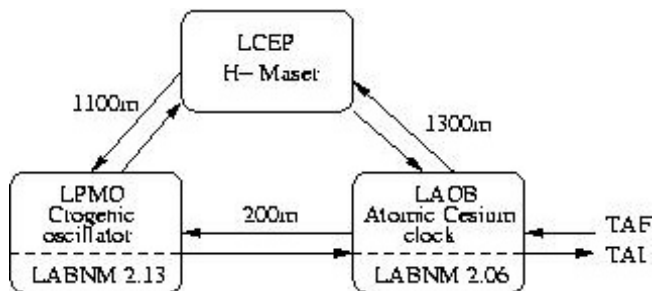


Fig. 1. Optical link between the three laboratories.

Typically it transfers better than 10^{-14} short term frequency in the 10-100s range. Best middle term stability is obtained using an Hydrogen Maser at the LCEP around $2 \cdot 10^{-15}$ at 1000s. Atomic Cesium Clock allow long term stability at the LAOB with $4 \cdot 10^{-15}$ for 10 days. Moreover, these Cesium are part of the French Atomic Clock (TAF) and International Atomic Clock (TAI).

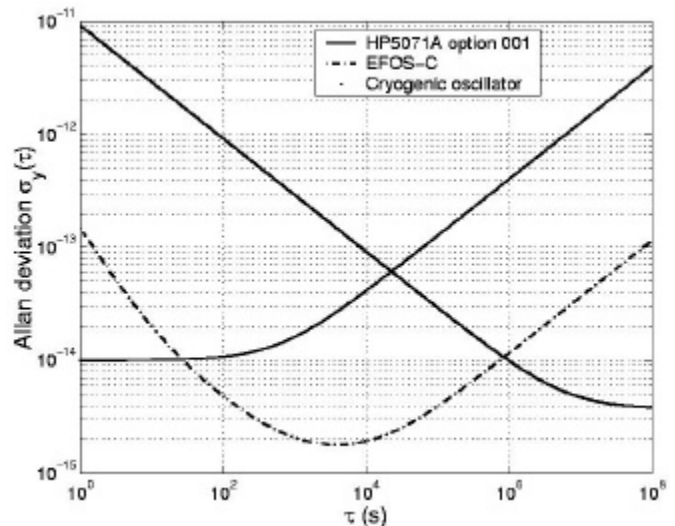


Fig. 2. Comparison of the stability of each reference in terms of Allan deviation $\sigma_y(\tau)$.

Optical fibers enable the use of the best performances by transferring the properties of the references. Optical links have been characterized by compensating the phase fluctuations into the fibers. The compensation corrects the long term fluctuations introduced by the fibers.

Comparison with and without closing the loop will be presented in this paper.

We analyse here the project of building an optical network that enables the use of the three different signals without degrading their stabilities. The signal is used to modulate the amplitude of the optic carrier that propagate into the monomode fibers. Each laboratory has a transmitter and a receiver in order to have the best frequency stability either on short, middle and long term. The optical link characterization and the compensation that correct the long term fluctuations introduced by the fibers are detailed in this article.

II. CHARACTERIZATION OF THE OPTICAL LINK STABILITY

Optical fibers link the three laboratories. Each site has a transceiver system that is required to use the reference signals at $\nu_0=100\text{MHz}$. The transmitter device located at the LPMO is modulated by a reference signal. It is demodulated at the LAOB and reinjected into another fiber. At the output of the receiver of the LPMO, the 100MHz signal has gone through a distance that is twice the one between LPMO and LAOB. Assuming the phase shift ϕ_f due to the fiber is the same for both fiber, we deduce that V voltage changed like $2\phi_f$. We use the following system [1-2] to characterize the optical link :

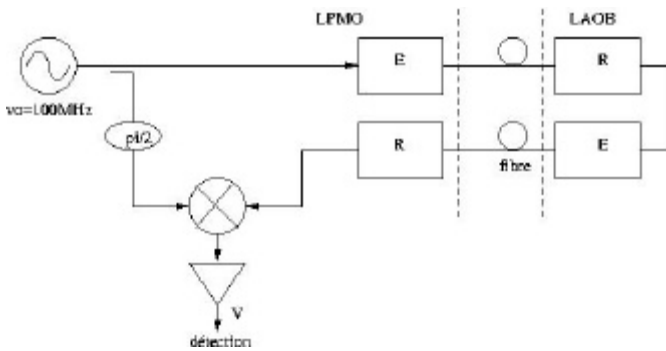


Fig. 3. Phase noise measurement bench for optical fibers

The spectral analysis of this voltage enables the evaluation of phase fluctuations that have been introduced by the optical link (fig. 4). Phase noise at 10Hz of the carrier is approximately $-128\text{dB}\cdot\text{rad}^2\cdot\text{Hz}^{-1}$. These fluctuations are mainly due to the laser Relative Intensity Noise (RIN). At this first step, this limitation has been considered as acceptable. Actually, in our experiment we are only trying to reconstitute the middle and long term frequency stability.

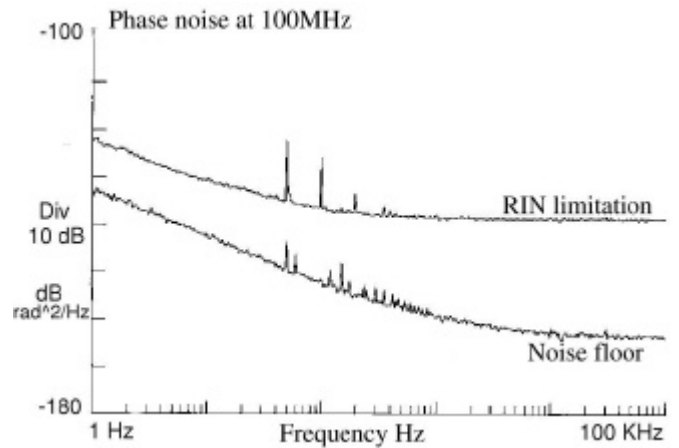


Fig. 4. Phase noise with (upper curve) or without optical link

The improvement concerning the short term stability (phase noise) will be possible either by using higher performance laser sources, or by a noise compensated system for the laser diode [3].

Long term stability is mainly limited by the thermal sensitivity of optical fibers [4]. There is a $7\cdot 10^{-6}$ relative phase shift for a 1°C temperature variation. For a 100MHz reference signal, the ultimate relative stability transferable to the receiver is then about $3\cdot 10^{-15}/\text{K}$. As the temperature probably varies more than 1°C , it is necessary to correct this phase shift.

III. PHASE CONTROL OF THE OPTICAL LINK

For the long term, the optical link stability is mainly limited by the variations of the optical length of the fibers. In order to correct these variations we have implemented the disposition shown on figure 5. The Voltage Controlled Shifter (DCT) allows to change the phase of the modulation signal in the laboratory where the transmitter is located. In this place, we assent to the $2\phi_f$ phase shift. A phase detection at $2\nu=200\text{MHz}$ enables to extract the error signal for the phase control.

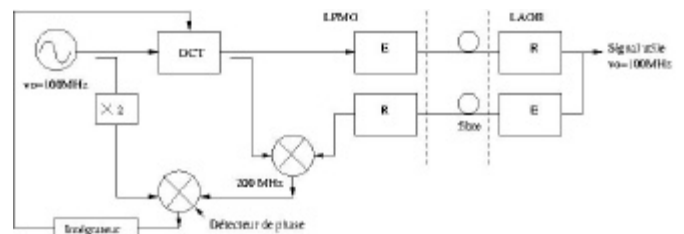


Fig. 5. Principle of the phase compensation

If $\Delta\phi$ is the phase correction brought by the DCT, the signal at the laboratory where the receiver is located will be $V_R \sin(2\pi\nu t + \Delta\phi + \phi_f)$. The signal received in the laboratory where we have the transmitter is then $V_R \sin(2\pi\nu t + \Delta\phi + 2\phi_f)$. This last signal is mixed with the reference signal $V_0 \sin(2\pi\nu t + \Delta\phi)$ in a first RF mixer that deliver a signal proportional to $\sin(4\pi\nu t + 2\Delta\phi + 2\phi_f)$. Finally the phase detection at 200MHz gives a voltage proportional to $2\Delta\phi + 2\phi_f$.

This tension is integrated and injected into the electronic control of the DCT. In the bandpass of the servo control, the condition of cancelling the error signal imposes $\Delta\phi = -\phi_f$.

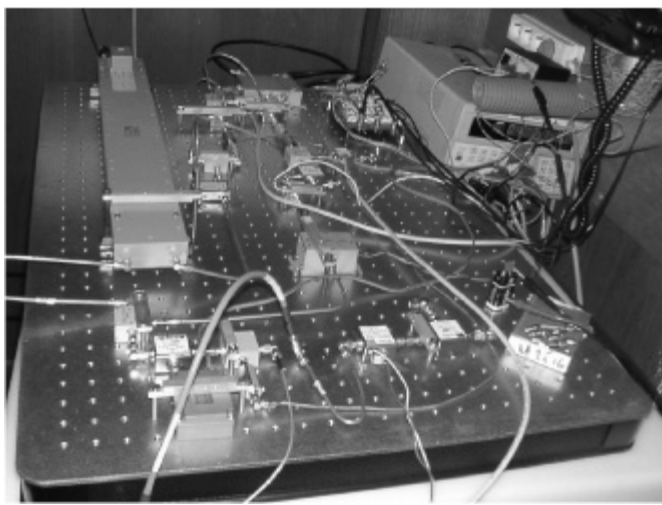


Fig. 6. Evaluation system.

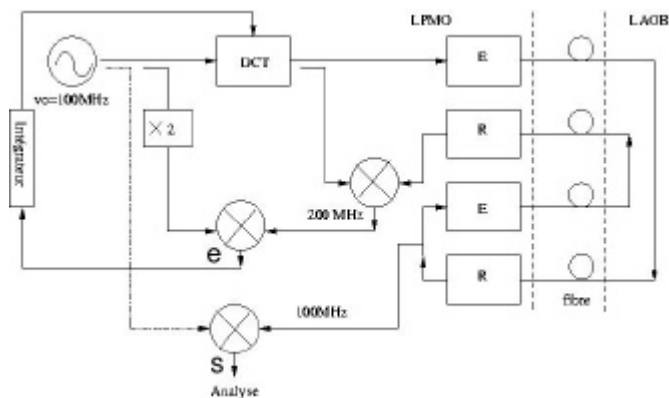


Fig. 7. Principle of the compensation with four fibers.

The signal in the site where we have the receiver is then corrected by the compensation of the phase fluctuations along the fiber. The evaluation system is shown in figure 6. To evaluate the performance of the correction, we use a system schematized on figure 7. Four parallel fibers are necessary to compare the signal to the

reference in a same site. The temporal analysis of the comparison signal 's' for the long term as indicated on figure 7.

Time deviation $\sigma_x(\tau)$ is given on figure 8 in open loop and closed loop versus integration time [5].

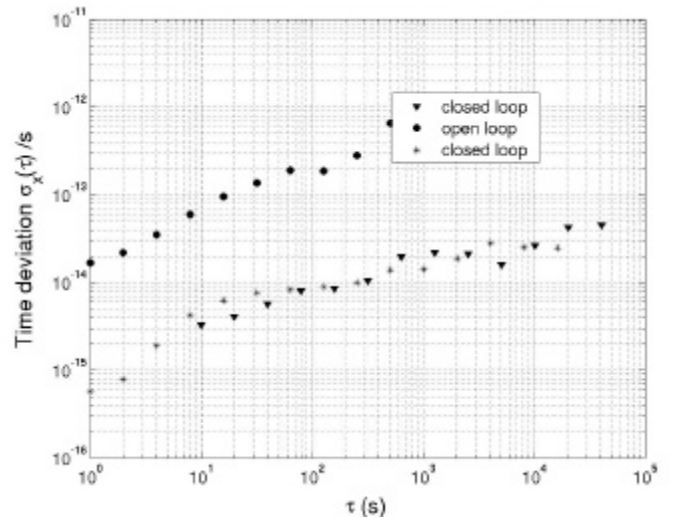


Fig. 8. Time deviation $\sigma_x(\tau)$

After one hour, the optical link without correction gives a drift that is corrected with the locking. Then it is possible to transfer the reference signals without degrading the frequency stability of the three different references.

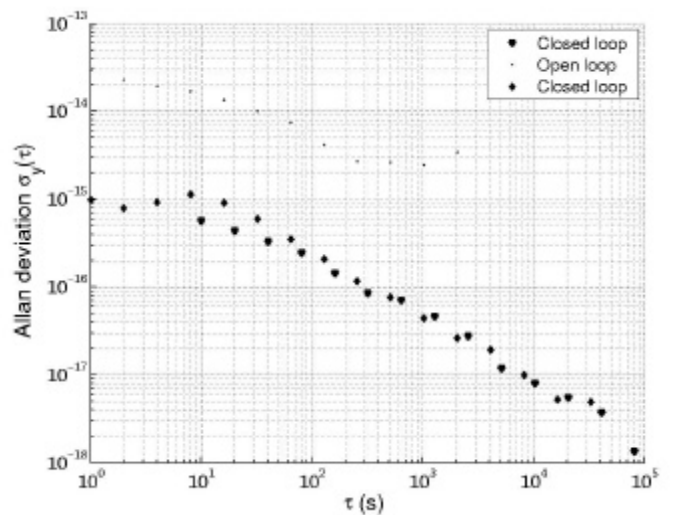


Fig. 9. Allan deviation $\sigma_y(\tau)$ with and without phase locking

We plan to assembly all the circuits in the same packaging to eliminate all the parasitic signals in order to obtain better results.

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