High performance frequency dissemination for metrology applications with optical fibers.

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***Abstract*—In this paper we describe the recent progress in the development of a high performance fiber based frequency distribution system for metrology applications. The fiber link operates at 100 MHz and 1 GHz and uses a standard telecom fiber of the Paris metropolitan network to disseminate the LNE-SYRTE frequency references over 44 km to the Laboratoire de Physique des Laser (LPL). Preliminary results of a 88 km compensated optical link is also presented.**

I. INTRODUCTION

Ultra-stable frequency sources play an important role in many modern metrology and fundamental physics applications. Very high sensitivity is required in many cases and thus, low noise and ultra stable oscillators and clocks are employed in for VLBI measurements, for the tests of Einstein's relativity, or for navigation. The opportunity of comparing clocks, even when the laboratories are separated by 100 km, could greatly help their accuracy evaluation. The objective is then to distribute frequency standards, without degradation of the metrological properties. From the late eighties, the Jet Propulsion Laboratory has paved the way of the development of fiber based distribution system for the Nasa Deep Space Network [1-3]. The astronomy community has demonstrated high performance fiber frequency distribution both for VLBI applications [4] and for modern telescope synchronization like the Atacama Large Microwave Array (ALMA). More recently the National Institute for Standard and Tecnology (NIST) have been connected with JILA using high performance optical link [5].

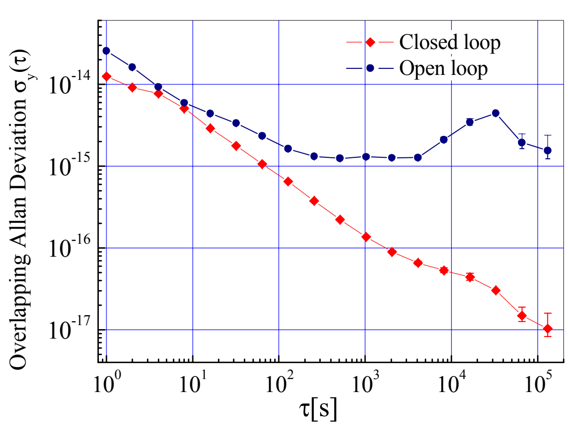

Figure1. Frequency stability of the 44 km optical link between the LNE-SYRTE and the LPL operating at 100 MHz (circles: open loop frequency stability, diamonds: closed loop frequency stability).

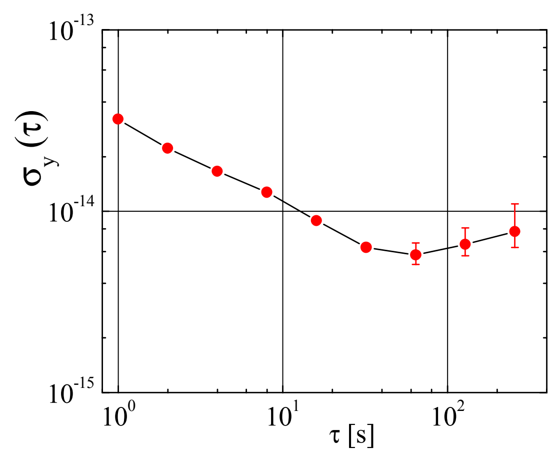

Figure 2 Frequency stability of the CO_2/OsO_4 optical frequency standard at the LPL compared to the LNE-SYRTE cryogenic sapphire oscillator via the 100 MHz optical link and a femtosecond comb optical synthesizer.

II. THE 100 MHZ DISTRIBUTION SYSTEM

In the past two years, we have developed a compensated fiber distribution system operating at 100 MHz with a short-term frequency stability of 1.5×10^{-14} at one second and 1×10^{-17} at one day integration time over 44 Km telecom optical fiber Fig1. We use this link to compare a Cryogenic

Sapphire Oscillator at SYRTE with a CO_2/OsO_4 (30 THz) optical frequency standard located at LPL [6]. This

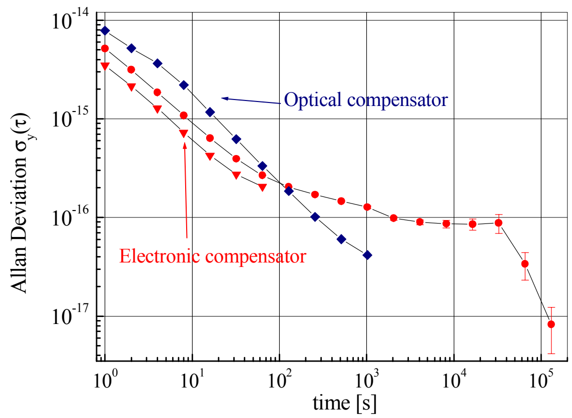

Figure 3 Preliminary frequency stability of an 88km optical link operating at 1 GHz.

comparison has demonstrated a resolution of 3×10^{-14} at 1 s (Fig.2) limited by the frequency stability of the optical

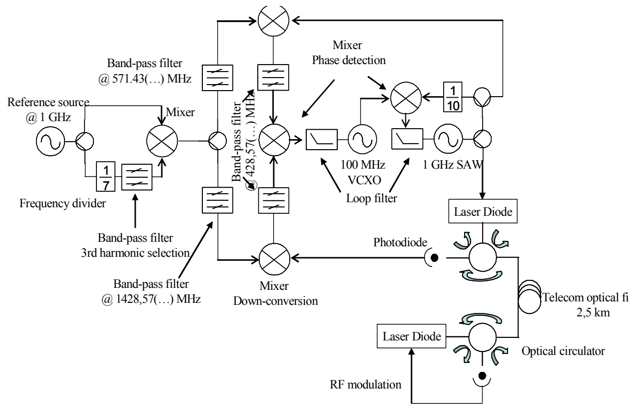

Figure 4 Schematic of the LNE-SYRTE electronic compensation system operating at 1GHz (JPL design).

standard. This is the first time where both short term and long tem frequency stability has been transferred over a standard telecom fiber.

III. The 1 GHz Distribution System

In order to improve the frequency stability we increase the modulation frequency. Recently we have demonstrated an optical transfer of a high performance reference signal over 88 km at 1 GHz via optical fibres of the Paris metropolitan network, with a frequency stability of about 3×10^{-15} at one second integration time (Fig. 3). This link uses the two 44km optical fibers between the LNE-SYRTE and the LPL. An electronic system developed at the LNE-SYRTE (Fig. 4) compensates phase fluctuations introduced along the link by external perturbations (temperature variations, mechanical vibrations). The long-term frequency stability is presently limited to about 10^{-16} by stray optical reflections. Moreover, the signal-to-noise ratio is degraded by Brillouin back-scattering (SBS). To overcome these limitations, optical filters based on fibre Bragg grating will be added to the system to reduce by 30-40dB, all parasitic terms. In this configuration, we expect to reach both short-term (3×10^{-15} at 1s) and long-term frequency stability, ($<10^{-17}$ at one day integration time). An optical compensation system developed by the LPL (Fig. 5) have demonstrated sub 10^{-14} frequency stability at 1s and a better long term performance (close to 10^{-17}) at one day integration.

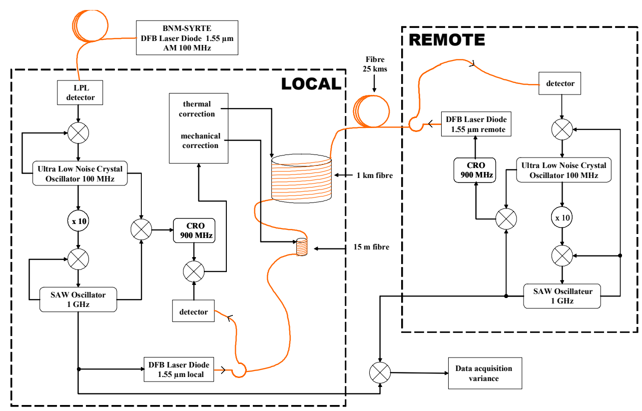

Figure 5 Schematic of the LPL optical compensation system operating at 1 GHz.

IV. Conclusions and Perspectives

The frequency stability transfer with standard telecom optical fibers over about 100 km is demonstrated. The long-term frequency stability of the link needs to be improved by

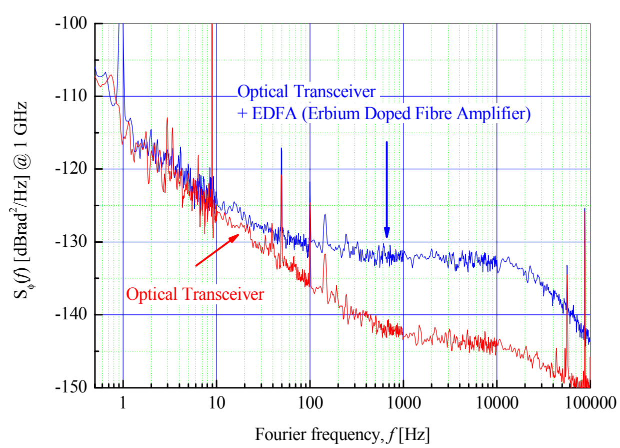

Figure 6 Preliminary phase noise measurement of a Erbium doped fiber amplifier (EDFA) for a modulation frequency of 1 GHz (red line is the laser source plus photodiode phase noise).

adding polarization scramblers and optical filters. The next step is to investigate the possibility to extend this link to a few hundreds of kilometres. In this way is possible to connect the major time and frequency laboratories across Europe. For this purpose we have recently evaluated the phase noise of an Erbium doped fiber amplifier (EDFA). The measurement is reported in Figure 6. The phase noise level is compatible with frequency stability below 10^{-14} at one second for a 1 GHz carrier. By connecting a few compensated segments of 100-200 km a transcontinental link of 1000-1500 km can be realized with projected frequency stability below 10^{-13} at one second and better than 10^{-16} at one day. The advent of high performance optical frequency standards based on single ion traps or optical lattice clocks with projected accuracies in the 10^{-17} range requires new comparison systems. This kind of optical link is a good candidate for such a purpose.

ACKNOWLEDGMENT

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