Progress and Undersampling In Digital Optical Frequency Control

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***Abstract*—We report on the recent progress in the development of digital implementation of Ultrastable Optical Frequency Controls, namely in the frame of experiments based on silicon cryogenic cavity, spherical Fabry-Pérot cavity, compact Ultra-Low Expansion (ULE) cavity and fiber link active compensation. With enhanced capabilities offered by the undersampling technique, we demonstrate similar performances but with a net gain in reconfigurability, flexibililty and dissemination over their analog counterpart.**

I. Introduction

For more than a decade, digital electronics has a massive impact on about every research field offering flexibility, robustness and reconfigurability. Numerous developments of complex scientific instrumentation now employ routinely partial or fully digital servo loops. Also, in the field of Time and Frequency, challenging aspects such as quantization noise and multi-input-multi-output (MIMO) systems are crucial for the development of clocks, oscillators, frequency transfer and timing systems. Techniques inherited from telecommunications and Software Defined Radio systems may push the current limitations a step forward. In this article we present recent progress on the development of fully digital frequency control of microwave photonics experiments [1] highlighting the extensive use of undersampling technique to remove unnessessary IF analog mixing stages, with no observed degradation. Digital implementations and interesting insights will be depicted in detail in the final proceedings.

II. Frequency Dissemination and Drift Compensation

One of the simplest optical system able to take advantage of a fully digital control system is the optical fiber link with active phase compensation. In this setup, the complete RF functionalities are fully integrated in standalone boards.

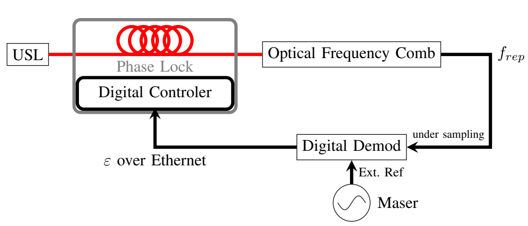

Fig. 1. Drift compensation of an ultra stable laser using an optical frequency comb and a hydrogen maser

The example presented in figure 1 is the compensation of the frequency drift of an ultra stable laser (USL), by taking as reference a hydrogen maser. Its long term stability is reported to the USL by acting on the links compensation.

The RF signal, which contains the phase disturbances information, is undersampled by the ADC. This method allow us to acquire RF signals up to few hundreds MHz with a sampling rate of 125 MHz. The correction, computed into the FPGA, is used to tune the frequency of a NCO. The output drives the AOM in order to cancel the phase fluctuations.

Figure 2 shows the frequency stability comparison of the repetition rate of an optical frequency comb without (purple curve) and with (green curve) the frequency drift correction. In the first case the drift of the USL is visible around 400 s, while in the second case the drift is not present.

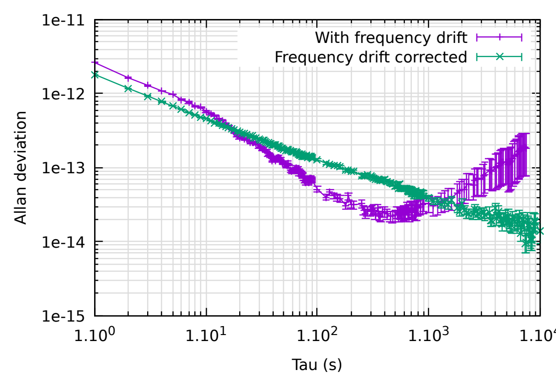

Fig. 2. Frequency stability of the repetition rate of an optical frequency comb with the drift compensation (green curve) and without drift compensation (purple curve).

The link compensation is performed with the use of a Michelson interferometer. The first arm of the interferometer is the fibered link with a phase noise to compensate, that ends with both a Faraday mirror and the link output. The second arm is a short reference arm made of a single Faraday mirror. An acousto-optic modulator is placed on the path of the fibered link for the phase correction.

The reference arm of the compensated link can constitute a limiting factor that must be taken into account in the phase noise of the output signal. We setup an experiment, presented in Fig. 3, that aims at estimating the phase noise induced by the reference arm which has been measured using the fully

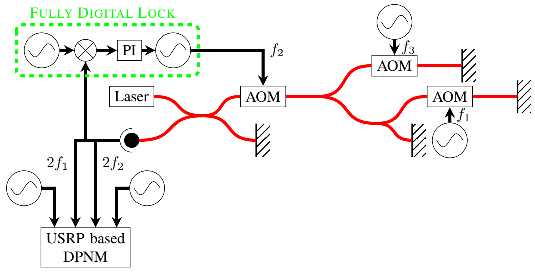

Fig. 3. Experimantal setup used to determine the phase noise induced by a reference arm in the link phase compensation

digital Digital Phase Noise Measurement System (DPNM) developped in [2] (Fig. 4).

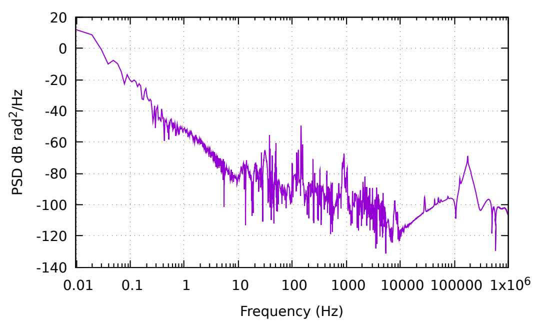

Fig. 4. Estimation of the phase noise of the reference arm of a Michelson interferometer.

III. Cavity Stabilized Lasers

An other interesting usage of a full digital control system is the frequency stabilization of a laser onto a Fabry-Perot cavity (Fig. 5). The common scheme is based on a Pound-Drever-Hall frequency discriminator, which uses phase modulation of the optical signal and demodulation to get an error signal.

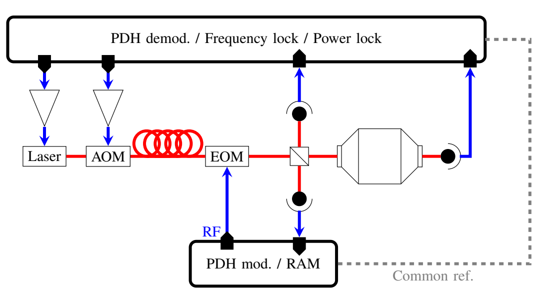

Fig. 5. Principle of the full digital PDH lock with a pair of boards

Thanks to the fast ADC and DAC, the demodulation part is integrated into the FPGA which generates the correction signals. To ensure a coherent modulation/demodulation, the two boards are referenced with the same external clock. The digital error signal is used by a set of PI controllers. The corrections are applied by multiple ways like frequency shift with an AOM or with a high voltage applied on a piezo-electric stack.

The fully digital PDH controller is used for the frequency stabilization on a cryogenic silicon cavity. A second digital controller with an analog demodulation is installed on a spherical ULE cavity based laser. A third laser based on a compact cavity is used to compare the relative frequency instability of those lasers.

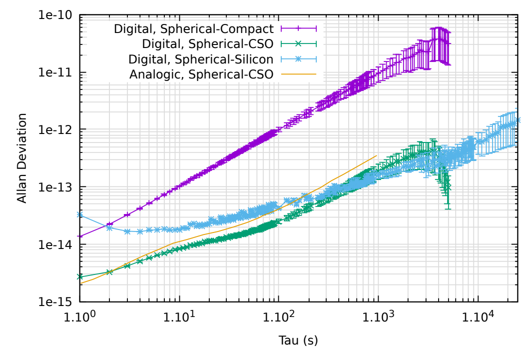

Fig. 6. Fractional frequency instability of several lasers

The measured fractional frequency instability of the spherical cavity based laser locked with the digital and analog way are similar (fig. 6). The analog instability comes from [3].

The performances of the silicon cavity based laser are lower than the spherical one above 300 s.

IV. Optical Phase Lock

At last, we will also report on a digital optical phase lock using RIO locked to an ultrastable laser whose preliminary result still present better performances in an analog version of the locking scheme (fig 7)

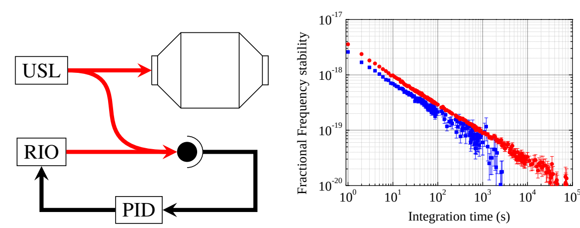

Fig. 7. Comparison between analog and digital lock of a RIO laser on a ultrastable laser. The upper curve represents the stability of the digital lock.

V. Conclusion

We report on the recent progress in the development of digital frequency control of ultrastable optical devices, with enhanced capabilities using undersampling technique. We demonstrate similar performances but with a net gain in reconfigurability and expansion over their analog counterpart.

VI. Acknowledgment

This work is supported by the ANR Programme d'Investissement d'Avenir in progress at the Time and Frequency Departments of FEMTO-ST Institute (Oscillator IMP, First-TF and Refimeve+).

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