Fully-digital implementation of a Doppler cancellation technique for local ultra-stable frequency dissemination

Martina Matusko[1], Ivan Ryger [1], Gwenaël Goavec-Merou[1], Jacques Millo[1], Clément Lacroûte[1], Émile Carry[1], Jean-Michel Friedt[1], Marion Delehaye[1]

1. *FEMTO-ST Institute, Besançon, France*

Fiber links have proven to be the most robust tools for ultra-stable frequency dissemination over various distance ranges, thanks to an active compensation of the fiber propagation noise [1]. Here, we present our setup for local ultra-stable frequency distribution within an institute, fully based on digital electronics. We use a Red Pitaya SDR^{lab}122 – 16 (RP16) platform to perform a Doppler cancellation scheme, based on a heterodyne Michelson interferometer using a single acousto-optic modulator (AOM) at 110 MHz, in order to cancel the phase noise arising from a 90 m-long fiber link at 1542 nm. The experimental setup is shown in Fig. 1.

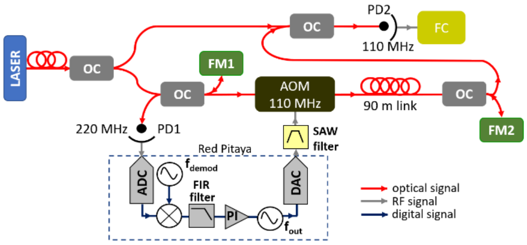

Fig. 1 Doppler cancellation setup. OC: optical coupler; FM: Faraday mirror; PD: photodiode; FC: frequency counter. PD1 measures a beatnote at 220 MHz which provides the phase disturbance information. PD2 detects a monitoring signal at 110 MHz.

To measure the noise arising from the fiber link, we compare the short reference arm of the interferometer with the long arm containing the fiber. The beatnote at 220 MHz (resulting from the return trip through the AOM) carries the phase noise information and is fed to the RP16 that generates the correction signal. To characterize this phase-locked loop, the output of the link is directly compared with the seed laser: the resulting beatnote at 110 MHz carries the uncompensated noise.

All the signal processing is done by the RP16 board clocked by a hydrogen maser. The 110 MHz correction signal and the 220 MHz beatnote signal are outside the Nyquist baseband of the RP16. To overcome this without environment-sensitive mixers and multipliers, we make a novel use of sampling properties offered by digital electronics: we directly undersample the 220 MHz input [2], and use an aliased image of the RP16 output to generate a 110 MHz spectral component.

Furthermore, we propose an original characterization method to measure the disturbance rejection and achieve the best noise cancellation performances, even when the remote end of the fiber is not accessible. Using this method, we set the proportional-integral gains and measured the frequency stability of the monitoring signal at 110 MHz in open and closed loop configurations in three cases (see Fig. 2): with a 90 m-long fiber link, with a 1 m-long long fiber link, and lastly, without the physical system consisting of fibers and the AOM. The stability for the closed loop measurement of the setup with the 90 m-long fiber is in the 10^{-18} range for all integration times, showing that this setup fully satisfies the requirement of local dissemination of an ultra-stable signal.

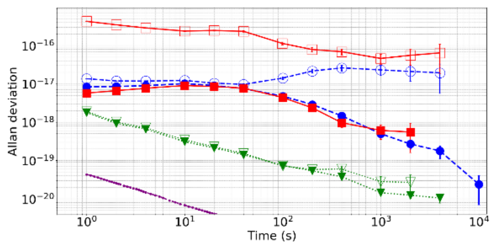

Fig. 2 Fractional frequency stability of the monitoring signal at 110 MHz scaled to 194 THz. Open symbols: free running system. Full symbols: closed-loop measurement. Green triangles: no physical system (see text). Blue circles: with 1 m link. Red squares: with 90 m link. Purple line: hydrogen maser used as an external clock for RP16. All measurements are done without any insulation.

Our setup proved to be suitable for local ultra-stable frequency distribution and its performance could be further improved by the use of a second AOM at the remote end of the fiber to discriminate undesirable reflections. In principle, with minor adjustments, it can also be used for longer links.

References

[1] E. Cantin et al., "An accurate and robust metrological network for coherent optical frequency dissemination," New J. Phys. **23**, 053027 (2021).

[2] S. Mukherjee et al., "Digital Doppler-cancellation servo for ultrastable optical frequency dissemination over fiber," IEEE Trans. Ultrason. Ferroelectr. Freq. Control **69**, 878-885 (2022).