Numerical investigation of the effect of optical discriminator nonlinearity in laser frequency locking on fiber delay line

Debanjan Show, Stéphanie Grabielle, Frédéric Audo*, Fabien Kéfélian

ARTEMIS, Université Côte d'Azur & Observatoire de la Côte d'Azur & CNRS, Nice, France

Email: debanjan.show@oca.eu

Optical interferometer based on fiber delay line can be used as an optical frequency discriminator[1]. This one has a sinusoidal response to the optical frequency, $U=U_{max}\sin(\Delta\Phi)$ with $\Delta\Phi=\varphi(t)-\varphi(t-\tau)$, where φ is the phase of the laser and τ is the delay. $[\sin(\Delta\Phi)-\Delta\Phi]$ is the nonlinear part of the discriminator response which can impact the noise performance when the interferometer is used for laser frequency locking. To measure the out-of-loop noise of the laser frequency locking onto a fiber delay line we have locked two 1542-nm RIO diode lasers on the same interferometer[2] using Pound-Drever-Hall technique and analyzed the beat note frequency noise. The out-of-loop noise measurements showed a higher noise floor compared to the in-loop noise floor. This may be attributed to the discriminator nonlinearity.

Based on past and new experimental data, here we performed new numerical simulations to quantify more precisely the effect of the discriminator nonlinearity on the noise floor. A noise signal is numerically generated with the measured spectrum of the in-loop error signal. Then arcsinus is computed to obtain the interferometric phase signal. Finally, the spectrum of the out of loop frequency noise is obtained using Welch method. We obtained very good agreement for 500 m length in double path configuration (Fig. 1 left). However, with shorter length and larger locking bandwidth, the computed noise level appears rapidly to be smaller than the experimental one (Fig. 1 right). We have then extended the bandwidth of the spectrum used for simulation to include noise components up to 100 MHz, which led only to small corrections. We have also investigated the impact of a discrete (unresolved) line in the spectrum. Our results show a cubic dependence of the induced noise floor on the line amplitude and a strong dependence on the frequency position of the line in the spectrum.

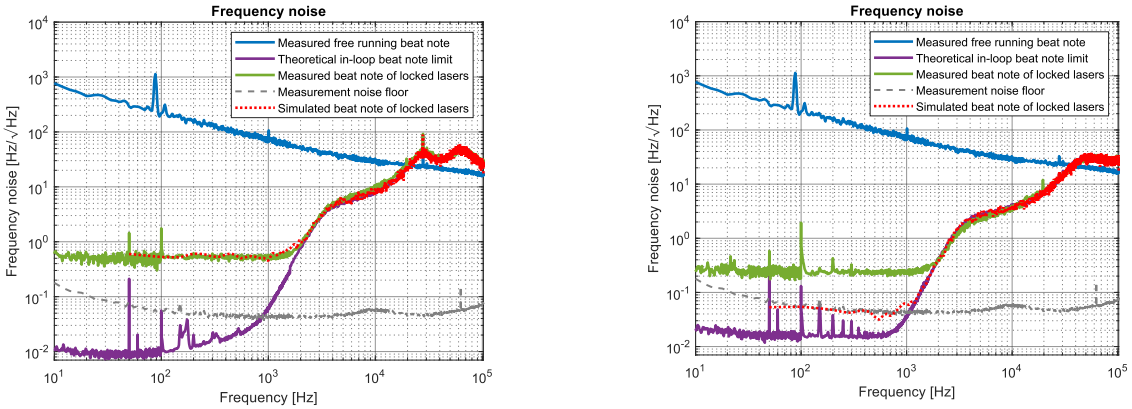

Figure 1: Frequency noise spectra. Left: 500 m fiber length, and right: 200 m fiber length.

[1] B. S. Sheard, M. B. Gray, and D. E. McClelland, "High-bandwidth laser frequency stabilization to a fiber-optic delay line," Appl. Opt., vol. 45, p. 8491-8499, 2006.

[2] F. Audo, J.-P. Coulon and F. Kéfélian, "Experimental evidence of a fundamental noise floor at the tens of millihertz level in laser locking onto unbalanced fibre-based Michelson interferometer," CLEO/Europe-EQEC, Munich, Germany, 2017

* F. Audo is now with CEA