Laser frequency stabilization using light-shift in vapor-cell clocks

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This paper describes the Light-Shift Laser-Lock (LSLL) technique, a novel method that greatly simplifies the laser setup of vapor-cell atomic clocks by stabilizing the pumping-laser frequency to the same atomic sample used in the clock operation. The method estimates and cancels out a controlled amount of light shift induced on the clock transition, that is proportional to the laser detuning[1]. More in detail, the method alternates two clock sequences with different light shifts and processes their respective error signals to simultaneously determine and then correct the detuning of both the local oscillator and, notably, the laser. One of the key features of the LSLL technique is the use of low-noise and FPGA-based electronics, enabling the implementation of the sophisticated clock sequence and the related real-time digital processing necessary to extract microwave and laser information from the atomic signal.

The LSLL technique has been specifically designed to be compatible with state-of-the-art 3-level clocks and has undergone experimental testing using the pulsed-optically-pumped (POP) vapor-cell clock at INRIM. The results have shown that the LSLL technique operates robustly, having a capture range of gigahertz without significantly compromising clock stability[2]. In our tests, the clock exhibited a white frequency noise of $3.2 \times 10^{-13}\,\tau^{-1/2}$ for averaging time up to 4000 s, reaching a floor below 1×10^{-14} up to 100 000 s (drift removed). These performance levels meet the requirements of next-generation Global Navigation Satellite Systems on-board clocks, and offer the added benefit of a reduced number of laser-system components, as well as increased reliability and robustness.

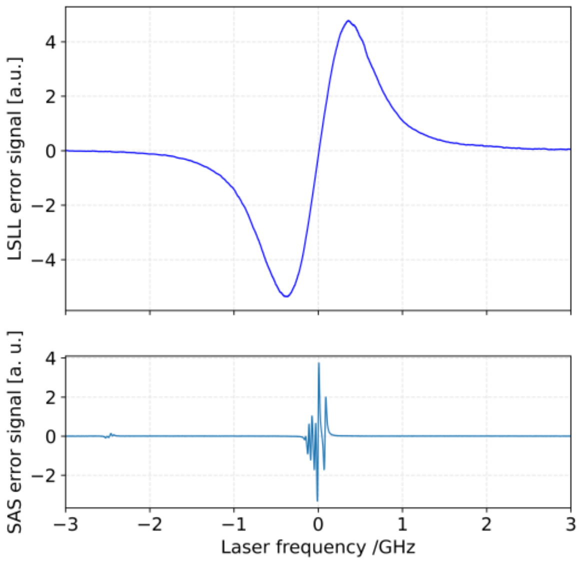

Fig. 1: Upper Plot: Error signal generated with the LSLL technique for locking the frequency of the pumping laser;

Lower plot: spectroscopy signal obtained in a conventional sub-Doppler saturation absorption (SAS) setup on an external cell filled with Rb (no buffer gas), for comparison.

[1] B.S. Mathur, H. Tang, and W. Happer. "Light shifts in the alkali atoms", Physical Review vol. 171, p. 11, 1968

[2] M. Gozzelino et al., "Realization of a pulsed optically pumped Rb clock with a frequency stability below 10-15", Scientific Reports, vol 13, p. 12974, 2023