Noise Analysis on Fiber Delay-based Laser Stabilization

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This study introduces an analysis of noise suppression in mode-locked lasers by employing a delay-based method to stabilize the repetition rate. The method utilizes a fiber-delay line reference and a feedback loop control based on the optical cross-correlation of ultra-short pulses. The paper discusses the effects of timing sensitivity of the detection, optical path length, feedback loop gain, and potential limitations.

The analysis is based on the experimental implementation shown in Fig. 1a, where laser pulses are split into an original pulse train and a counterpart that passes through a delay line reference. Relative jitter between the two paths is measured using a balanced optical cross-correlator (BOC) that has high timing sensitivity. This allows for the detection of timing differences between the original and delayed pulse trains with unprecedented precision. The BOC utilizes a waveguide with an integrated Periodically Poled Potassium Titanyl Phosphate (PPKTP) module. This system exhibits a high sensitivity to timing jitter, which is significantly greater than that of traditional bulk-optic based methods[1]. Figure 1b illustrates the feedback loop model used to study the reduction of timing jitter. The feedback loop utilizes the output from the BOC as an error signal to control the laser's intracavity piezoelectric transducer (PZT) with the use of a loop filter controller. This process locks the laser's repetition rate to the fiber delay reference and reduces timing jitter significantly. This study concentrates on analyzing the extent of noise reduction achievable through this method. The reduction is influenced by various key factors, such as the timing sensitivity of the optical cross-correlator, the optical path length, and the feedback loop gain.

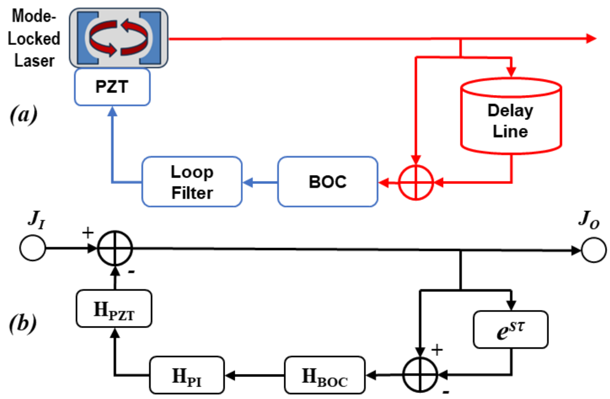

Fig. 1: (a) Setup for delay-based laser repetition rate stabilization. (b) Feedback model for jitter suppression analysis. JI: inherent laser jitter when there is no feedback; JO: laser jitter when the feedback control is active; BOC: Balanced-Optical Cross-correlator, HBOC, HPI and HPZT: transfer functions of BOC, PI controller and laser PZT, respectively.

Additionally, our investigation delves into the limitations of this control system and offers experimental validations. We provide a comparison with in-lab implemented results and highlight the distinctions from other techniques employed for laser stabilization.

[1] K. Şafak et al., "Photonically referenced extremely stable oscillator," Opt. Lett., vol. 49, no. 4, p. 977, Feb. 2024