Title

Review Paper for Feed-Forward-based Carrier-Envelope Phase Stabilization

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ABSTRACT

In the mode-locked laser, where a single pulse circulates in the laser resonator to generate the pulse train, carrier-envelope phase (CEP) and time jitter are usually unavoidable and influence the output signal performance. This paper will discuss how the feedback (FB) and feed-forward (FF) systems help control and stabilize the CEP [1].

I. INTRODUCTION

In mode-locked laser cavities, pulses often propagate with carrier-envelope offset phases (CEO), instead of perfect multipliers of 2π period, and cause different relative positions between the carrier wave and envelope during each round trip due to the chromatic dispersion, pump fluctuation, and thermal drifts [1]. Also, varied CEP leads to frequency shifts as varied carrier-envelope offset (fceo), and makes different frequency comb lines spacings [1]. The FF part uses an acoustic-optic frequency shifter (AOFS) to correct CEP fluctuations, reduce time jitters, and stabilize lasers in the short term [1]. The FB part feeds proportional-integral-derivative (PID) controllers to adjust pump power and cavity length to constrain frequency drifts in the long term (75 hours) [2].

II. METHODS

Based on f-2f interferometry, we can detect fceo=2*(n*frep+fceo)-(2*n*frep+fceo) between 2*fn (second harmonic generation, SHG) and f2n (supercontinuum generation SCG) [1]. In the FF part, it replaces the varying fceo=frep*δΦmod(2π)/2π different for each cycle with fixed faofs=fceo+flo =80MHz for stabilizing but is limited by several hundred kHz bandwidth [2]. The FB system helps generate an error signal between a local oscillator fset and faofs as ferror=faofs-fset with ferror ranges from 0kHz to 500kHz and feeds it to a PID controller [2]. Thus, FF ensures short-time high CEP stabilization while FB's offset keeps recalibrating cavity conditions to avoid long-term phase drifts from the laser and temperature, humidity, and pressure parameters [2].

In Matlab codes of mode-locking lasers for classes, we focus on the total dispersion, energy density, saturable absorption, and cavity length to tune the repetition rate, pulse duration, and central wavelength performance. Instead of using the constant faofs with FF, we need to tune the path length and pump power for each cycle to achieve fceo as a multiplier of 2π for optimal mode-locked conditions. However, that is not possible as only small fluctuations can be made for each tuning as the laser needs tens or even hundreds of round trips to get a steady state and it is hard to accompany with background variables for long-term stabilization.

Based on f-2f interferometer to reduce CEO, AOM causes limited spectral width, the DC stabilizer brings 1/f noise, and the phase-lock two beat notes to each other aims to make fceo=0 to solve such issues [3]. The periodically poled lithium niobate (PPLN) crystal applies frequency doubling, polarizing beam splitter creates frep, frep-fceo, frep+feco on s polarized path and frep on p polarized path, the double-balanced mixer (DBM) based on DC voltages for zero crossing error signal mixes the split signals, and the PID feeds proper injection current to the pump laser diode to make fceo=0 without AOM or difference frequency generation (DFG) [3].

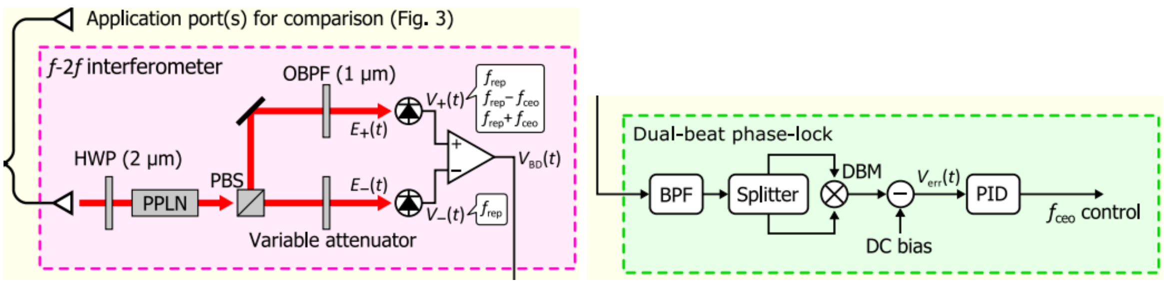

Figure 1. Schematic for generating an offset-free comb [3].

III. RESULTS AND DISCUSSION

Based on the FF and FB system with manually adjusting pump power for every half an hour to keep faofs within 80 ± 0.25 MHz, the laser achieves the IPND of 3.5 mrad, timing jitter of 2.9 as (1 Hz – 3 MHz), and stabilization over eight hours [1]. For a better-designed automatic FB part, the integrated phase noise of 14 mrad (1 Hz to 3 MHz) over 75-hour stabilization is accomplished [2]. A simple phase-lock two beat notes as (frep+fceo)=(frep-fceo), a phase shift fceo of 0.00075 ± 0.1 Hz for gate time of 25000s and frep of 29.9 MHz is achieved [3].

IV. CONCLUSION

Through both the inside FB loop and outside FF loop, we find the mode-locking laser can be stabilized with an ultralow time jitter for a long term even considering all the frequency drift, temperature, humidity, and pressure issues. With the accurate and consistent mode-locking laser, we can then form high-quality frequency combs for microcosm frequency, time, and length measurements as well as communication and spectrum studies for the environment.

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Reference

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