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Review of Carrier-envelope phase stabilization techniques for Er:Yb:glass lasers via feed-forward technique

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Abstract: Randy Lemons, et. al demonstrate a feed-forward technique to achieve long-term carrier-envelope phase (CEP) stabilization in a SESAM mode-locked Er:Yb:glass laser at 1.55um with a timing jitter of 2.9 (1Hz-3MHz) over a period of 8 hours.

INTRODUCTION

The rise of few-cycle pulsed lasers, particularly in applications that require phase consistency and shot-to-shot timing, highlights the need for excellent stabilization of the carrier-envelope phase (CEP). Ultrashort few-cycle pulses are useful for generation very high peak powers with only moderate peak energies. For example, a 10-fs pulse with only 10 mJ energy has a peak power of the order of 1 TW = 1000 GW. Higher peak powers are important for studying high-intensity physics, such as multi-photon ionization, high harmonic generation, or the generation of even shorter pulses with attosecond durations.[2]

SESAM stands for semiconductor saturable absorber mirror – its key property is that its optical absorption coefficient decreases at higher optical intensities. In semiconductors, such a nonlinear absorption can be caused by excitation of electrons from the valence to conduction band, which reduces absorption of photons with energy just above the bandgap energy.[3]

SESAM lasers utilize this property to enhance light modes that are supported by the cavity and discourage modes that are poorly supported. This phenomenon stabilizes into a mode-locked laser, which produces ultrafast fs-range pulses with broad linewidth. Often the pulse duration is orders of magnitudes smaller the pulse spacing, which allows peak powers orders of magnitude higher than the average laser power.[4]

However, mode-locked lasers exhibit a shot-to-shot CEP slippage ("shot" and "pulse" are used interchangeably photonics), which arises from intracavity environmental conditions and fluctuations in optical power. In a single shot, these differences result in a difference in the phase and group velocities. The relative shift between the peak electric field and the envelope is known as the CEP, constrained from 0 to 2π. In a free-running mode-locked laser, the intracavity conditions vary from shot-to-shot and cause the CEP to be unstable.[1]

There are two sets of control techniques to stabilize these conditions and thus the CEP: *feedback* methods measure the output and adjust parameters such as pump power or cavity length accordingly. *Feed-forward* methods stabilize the CEP by acting on the output pulses rather than the internal activity. They do this by feeding the beat signal to an acousto-optic frequency shifter (AOFS) outside of the cavity to phase-modulate the laser frequency spectrum.[1]

METHODS

For their source laser, Randy et. al used a SESAM soliton mode-locked Er:Yb:glass laser oscillator (OneFive ORIGAMI-15) in their feed-forward (FF) system. The oscillator delivers 140 mW of power in 175 fs pulses at a repetition rate of 204 MHz with a spectral bandwidth of 14.9 nm centered around 1.55 μm.

The AOFS used was AA Opto-Electronic MGAS80-A, estimated to have a bandwidth of 500kHz based on the manufacturer listed sound velocity of 2520 m/s. The light from the source oscillator is split between an in-loop feedback measurement and the AOFS plus out-of-loop measurement. (Figure 1)

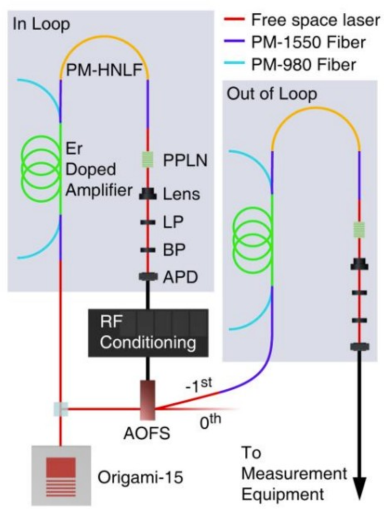
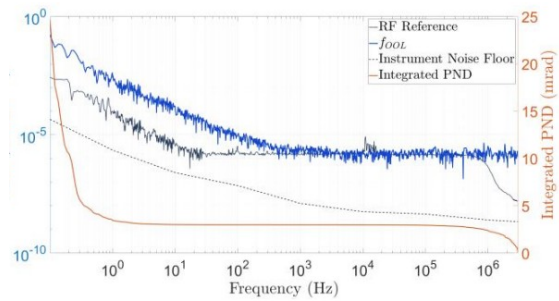


Fig. 1. Experimental setup with in-loop and out-of-loop beamlines. The Erbium doped amplifiers are fed with 14 pin butterfly diodes at 980 nm.[1]

Fig. 2.



Single side band phase noise spectral density (PND) plots of □□□ (grey) and □□□□ (black). IPN(orange)is shown on the right vertical axis.[1]

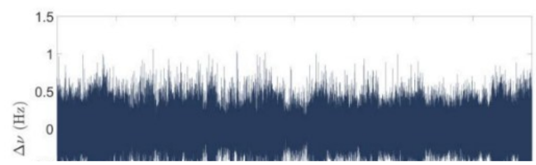


Fig. 3. Eight-hour frequency drift of the stabilized OOL signal relative to the set point of □□□ showing 0.16 Hz rms variance during a typical workday.[1]

After splitting, both beams are connected to stretcher fibers, then Er:fiber amplifiers to improve SNR. After amplification, pulses are recompressed to a 60fs duration with 250mW average power using PM-1550 HNLF fiber. The signal is then passed to avalanche photo diodes (APD) for electronic detection. The signal is then RF conditioned to be in the operational range of the AOFS (80 ± 2.5 MHz). After filtering, the signal is mixed with a 10MHz local oscillator, passed into a divider to create a comb of frequencies increasing from 1.4MHz in 1.465MHz steps. A line of this comb is chosen depending on the current laser pulse frequency, and mixed with a bandpass filter to create a 80MHz final signal. This signal is then amplified to 26dBm to drive the AOFS in the OOL beam, which subtracts the drive signal from frequency comb and shifts the power to the AOFS 1st-diffraction order. The final signal is then filtered for analysis.

RESULTS AND INTERPRETATION

Using this setup, Randy et. al was able to achieve IPND of 3.5 mrad and a Δ□□□□ of 2.9 as, which is significant improvement to previously reported values for Er lasers via the FF method.[1]
However, a natural slow drift in the beat signal required the pump power to be adjusted every half hour to maintain f_{AOFS} in the 80 ± 0.25 MHz range.

CONCLUSIONS

Randy et. al was able to make a significant improvement to currently reported CEP jitter for Er lasers via the FF method. Additionally, they claim that can be readily resolved with a slow feedback PID controller to adjust pump power.

It would appear that in this case some combination of FF and FB controls yield the best results; FF for the short-term CEP stabilization, and pump FB to control long-term drift. Perhaps this approach could be for other ultrashort mode-locked lasers to maximize timing performance.

It would also appear that signal amplification is key to the improved performance of this set up over an earlier one referenced by Kundermann et al[5] due to redmuced shot noise.

For future experiments, I would have these questions: what happens if the Er:fiber amplifiers are removed? Is the effect of shot noise quantifiable? Can this setup potentially be made more compact for real-world applications? What is the effect of physical vibration on this system? What is the jitter of the AOFS and can it be potentially reduced?

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