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Publication Date

2026-06-07

Supplemental Material

<https://escholarship.org/uc/item/9sv7x7nb#supplemental>

Data Availability

The data associated with this publication are in the supplemental files.

Validating Single-Pulse Stability of the SESAM Mode-Locked Er:Yb:glass Oscillator Underlying Feed-Forward CEP Stabilization

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Abstract: This review examines Lemons et al. (2019). I adapt the class linear-cavity SESAM model to the ORIGAMI-15 Er:Yb:glass laser, confirm stable single-pulse operation, reproduce its 175 fs soliton, and map the multipulsing boundary.

INTRODUCTION

Feed-forward (FF) stabilization of the carrier-envelope phase (CEP) is one of the most striking recent results in frequency-comb work. Lemons et al. apply it to a SESAM soliton mode-locked Er:Yb:glass oscillator (Onefive ORIGAMI-15) and reach a timing jitter of 2.9 from 1 Hz to 3 MHz at 1550 nm, with eight hours of stability [1]. The method is attractive because it acts on the output comb through an acousto-optic frequency shifter and lets the cavity evolve on its own, but it has an assumption. The f - $2f$ beat note encodes a single, well-defined offset frequency only if the oscillator emits exactly one pulse per round trip. If the laser enters multiple-pulse operation, the comb can develop additional modulation and the f - $2f$ beat may no longer represent a unique f_{CEO} . The paper does not explicitly test this single-pulse stability margin.

I test that assumption directly. Starting from the linear-cavity SESAM model from class [3], I adapt it to the reported ORIGAMI-15 parameters and ask three questions: Are the quoted 175 fs duration and 14.9 nm bandwidth self-consistent? Does the model settle into a stable single pulse near 1550 nm? How hard can the laser be driven before it transitions to two-pulse (or more) operation? The third answer matters for the paper itself, because the authors keep the system locked by raising the pump power by hand, and that adjustment moves the laser along the very axis that controls multipulsing.

METHODS

The model solves the generalized nonlinear Schrödinger equation with the fourth-order Runge–Kutta interaction-picture method [6] and an adaptive step size [7]. On each pass the field crosses a saturable-gain segment with parabolic filtering, reflects from a SESAM modeled with slow and fast saturable-absorber rate equations, and exits through an output coupler. To match the geometry of the real laser, I convert the class ring model into a linear standing-wave cavity. In this configuration the gain and dispersion are traversed twice per round trip, while the SESAM and the output coupler act once [3]. I represent the bulk Er:Yb:glass crystal and its anomalous intracavity dispersion with a short effective gain segment that carries half of the net round-trip group-delay dispersion (GDD) on each pass, and I set the Kerr coefficient from the intracavity mode area. The field grows from noise over a few hundred round trips.

Two analytic tools from class anchor the simulation. The time-bandwidth product (TBP) shows whether a pulse is bandwidth limited, and for a sech^2 soliton the limit is 0.315. The soliton-area theorem, $E_{\text{sol}} \approx 2|\beta_2|/(\gamma\tau_0)$, sets the energy a single fundamental soliton can hold at duration τ_0 for a given GDD and nonlinearity. Once the intracavity energy passes that cap, the cavity gains energy more cheaply by splitting into a second soliton [4,5]. To locate that point, I sweep the round-trip gain upward in small steps and seed each step from the previous steady state, which follows the single-pulse branch until it breaks.

RESULTS AND INTERPRETATION

I first check whether the reported numbers agree with one another. For 175 fs at 14.9 nm near 1550 nm, the spectral width is 1.86 THz and the TBP is 0.326, within four percent of the 0.315 sech² limit. The output is therefore a nearly bandwidth-limited soliton, exactly what soliton mode-locking should produce, and the 140 mW average power at 204 MHz works out to 0.69 nJ per pulse. The paper does not report this check, which confirms the quoted duration, bandwidth, and power are mutually consistent.

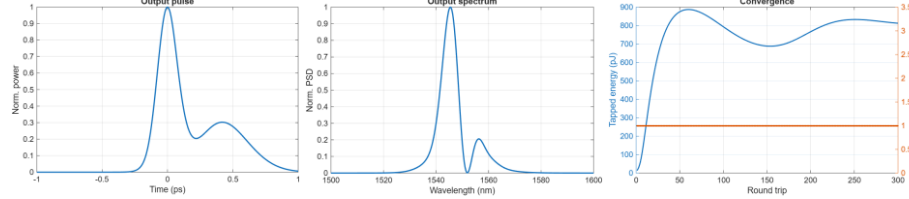


Fig. 1. Converged single-pulse operation of the adapted linear-cavity model: (a) stable ~ 190 fs pulse, (b) output spectrum near 1550 nm, (c) round-trip convergence with the pulse count pinned at unity.

Tuned to these parameters in the low-nonlinearity regime that stands in for the bulk crystal, the cavity converges to a stable single pulse of about 190 fs near 1550 nm (Fig. 1). This is comparable to the 175 fs operation to within accuracy of a lumped model, and the pulse count stays at one for every round trip once the field settles. A weak trailing dispersive wave and a small spectral side-lobe appear, familiar marks of a soliton perturbed once per round trip; they shrink as the nonlinearity drops, consistent with the single-lobe spectrum the authors report.

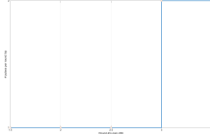


Fig. 2. Single-to-multiple-pulse boundary from an adiabatic gain up-sweep. The pulse count remains at $N = 1$ until about 3 dB round-trip gain, then jumps to $N = 2$.

Pushing the cavity harder shows where single-pulse operation ends. The single soliton holds until roughly 3 dB round-trip gain, or about 1.5 dB above the simulated threshold, where the pulse count jumps from one to two (Fig. 2). This agrees with the soliton-area picture: once the intracavity energy exceeds the single-soliton cap, splitting becomes favorable [4,5]. Since the cap scales as $|\beta_2|/(\gamma\tau_0)$, the low nonlinearity of bulk Er:Yb:glass helps keep the oscillator single-pulsed and makes it a strong CEP seed. This point is underemphasized by Lemons et al., who credit the performance mainly to low timing jitter. The result also exposes a tension in their long-term scheme. They recenter the AOFS frequency by manually raising the pump about every thirty minutes, which they note injects large phase noise. Since pump power is represented by the gain axis, each adjustment nudges the laser toward the multipulsing boundary; the slow pump-power controller used in their follow-up work [2] is therefore the better fix.

CONCLUSIONS

Adapting the class model to the ORIGAMI-15 settles the main questions. The reported 175 fs duration and 14.9 nm bandwidth are self-consistent with a nearly transform-limited soliton (TBP = 0.326), and a stable single pulse is the state the model naturally reaches. Under increased gain, single-pulse operation survives to about 3 dB round-trip gain, or roughly 1.5 dB above the simulated threshold, before transitioning to two-pulse operation. The low nonlinearity of the bulk Er:Yb:glass medium raises the single-soliton energy cap and helps explain why this oscillator is a strong CEP seed. The main limitation of my analysis is the lumped, fiber-derived model. Matching the true intracavity GDD and SESAM specifications, which the paper omits, and adding quantum noise to connect single-pulse stability to the measured CEP jitter are the natural next steps.

REFERENCES

1. R. Lemons, W. Liu, I. Fernandez de Fuentes, S. Droste, G. Steinmeyer, C. G. Durfee, and S. Carbajo, "Carrier-envelope phase stabilization of an Er:Yb:glass laser via a feed-forward technique," *Opt. Lett.* 44, 5610-5613 (2019).
2. J. Hirschman, R. Lemons, and S. Carbajo, "Long-term hybrid stabilization of the carrier-envelope phase," *Opt. Express* 28, 34093-34103 (2020).
3. D. T. Nguyen, *Modeling and Design of Photonics by Examples Using MATLAB* (IOP Publishing, 2021), Chap. 4.
4. H. A. Haus, "Mode-Locking of Lasers," *IEEE J. Sel. Top. Quantum Electron.* 6, 1173-1185 (2000).
5. F. X. Kärtner, J. Aus der Au, and U. Keller, "Mode-Locking with Slow and Fast Saturable Absorbers – What's the Difference?," *IEEE J. Sel. Top. Quantum Electron.* 4, 159-168 (1998).
6. J. Hult, "A fourth-order Runge–Kutta in the interaction picture method for simulating supercontinuum generation in optical fibers," *J. Lightwave Technol.* 25, 3770-3775 (2007).
7. O. V. Sinkin, R. Holzlöhner, J. Zweck, and C. R. Menyuk, "Optimization of the split-step Fourier method in modeling optical-fiber communications systems," *J. Lightwave Technol.* 21, 61-68 (2003).