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Self-Optimizing Mode-Locked Laser using a Genetic Algorithm

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Abstract: We apply the concept of natural selection to intelligently find optimum operating regimes in a fiber laser – a multi-parameter space. Using a compound fitness function we reliably achieve self-optimizing mode-locked operation.

OCIS codes: (140.3425) Laser stabilization; (140.3510) Lasers, fiber; (140.4050) Mode-locked lasers.

1. Introduction

Mode-locked fiber lasers have become essential tools in a diverse range of applications that require stable trains of ultrashort pulses. While many configurations exist for achieving pulsed operation, one of the first reported schemes – the Figure-8 (F8) laser [1] – is currently receiving renewed attention as a compact, flexible and economic, all-fiber femtosecond source, requiring only standard fiber components [2]. F8 lasers consist of a bidirectional and unidirectional ring. The bidirectional ring forms a loop mirror that is imbalanced (either actively or passively) to induce a differential phase, and consequently a power-dependent reflectivity that mimics the action of a saturable absorber, promoting pulses in the main laser cavity. To achieve stable self-starting operation, polarization control (PC) that acts as a phase bias is often included in the loop mirror to allow optimization of the effective saturable absorber behavior. Through adjustment of the bias, various regimes of operation can be traversed: continuous-wave (CW); Q-switched (QS); mode-locked (ML); and a variety of intermediate or unstable pulsating states. In additional to polarization, a variable gain in the loop mirror, as well as external perturbations, affect the bias level; therefore, achieving a strong nonlinear transfer function to yield and maintain stable mode-locking is a multi-parameter global optimization problem that can vary unpredictably over time – one of the major limitations of interferometrically mode-locked systems for practical applications. The problem of global optimization towards a target regime in a complex multi-parameter space can be mitigated, however, with the inclusion of electronic polarization control (EPC) intelligently managed using machine learning principles [3]. Genetic algorithms (GAs) are well suited to this task, and have recently been applied in the context of lasers [4]. Here, for the first time, we develop a genetic algorithm based on a compound fitness function to self-optimize a femtosecond F8 laser.

2. Algorithm development

Genetic algorithms apply the concept of natural selection from evolutionary biology to evolve a complete set of system parameters (or chromosomes) towards maximal system performance, quantified by a fitness function evaluated for each chromosome. An initial population of randomly valued chromosomes is tested against the system. Fitter chromosomes are selected and bred through successive generations to optimize system performance. Mutations are applied to prevent the algorithm from converging on local maxima.

Integral to the success of the algorithm is the choice of fitness function. To date, singular diagnostics, e.g. the peak of the fundamental radio frequency (RF) spectrum or the maximal second harmonic power, have been utilized to evaluate fitness; however, these metrics have proven insufficient to repeatedly achieve mode-locking [4,5]. We propose a compound fitness function, based on the RF peak height and the width of the optical spectrum, providing improved suppression of undesirable regimes, with little computational overhead.

3. Self-optimizing laser

We demonstrate the ability of our algorithm using a F8 laser [Fig. 1(a)] that comprises: a passive unidirectional ring containing an isolator, bandpass filter (12.8 nm bandwidth centered at 1560 nm) and 10% output coupler; and an active bidirectional loop, where gain is provided by a section of erbium fiber and the polarization is controlled electronically using an EPC [based on four stepper-motor-activated fiber-loop quarter waveplates (QWPs)].

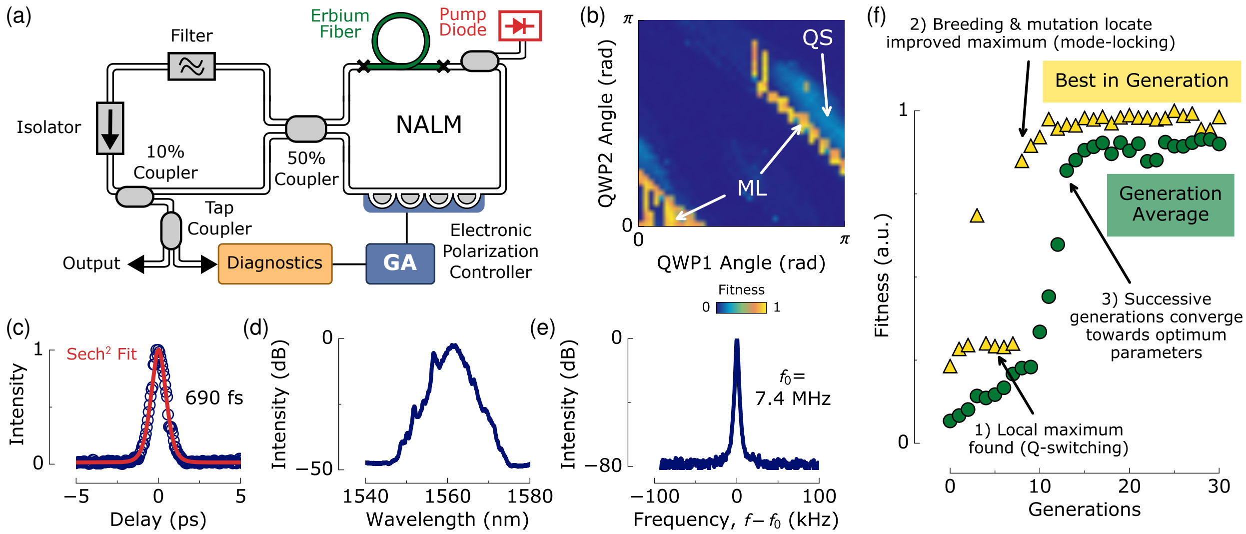

Fig. 1. (a) Cavity schematic. (b) Map of fitness values in a subset of parameter space. (c) Autocorrelation, (d) optical spectrum and (e) RF spectrum in a stable fundamental mode-locking regime. (f) Evolution of fitness score, demonstrating convergence of successive generation's average value towards the maximum, using our genetic algorithm. NALM: nonlinear amplifying loop mirror.

At a fixed gain, a wide range of operating regimes including, non-lasing, CW, QS, ML and noisy pulsation, can be accessed by varying the settings of the EPC. The sparseness of stable states within the broad range of parameters is exemplified in Fig. 1(b), which shows a map representing a two-dimensional slice of four-dimensional space evaluating the compound fitness, and highlights the complexity of the mode-locking problem. Localized regions of fitness identify stable mode-locked regimes, the steady-state parameters of which are shown in Fig. 1(c)-(e), where the autocorrelation, optical spectrum and fundamental RF spectrum are plotted.

We apply the GA to manage the EPC, leading to stable mode-locked operation after a number of minutes when initiated from any arbitrary initial system state. A representative evolution of the fitness over thirty generations shows convergence of the mean to the maximum value [Fig. 1(f)]. Due to genetic mutation, the algorithm is resistant to local maxima, which represents Q-switched or unstable pulsed operation; however, we note that for successive turn-on events the optimal solution found does not always represent single-pulse mode-locking, rather harmonic or multi-pulse regimes are occasionally observed. Future work is considering the development of a more sophisticated compound fitness function to accurately and persistently achieve stable, ultrashort pulse, fundamental mode-locking.

4. Conclusion

We have reported a genetic algorithm, using a compound fitness function, for fully-automated tuning of a fiber laser to achieve mode-locked operation – solving a multi-parameter global optimization problem. While we demonstrate the robustness of this approach on a fiber F8 laser, we anticipate the technique has general applicability to a wide-range of laser optimization tasks.

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