Interaction of Spatial and Temporal Cavity Solitons in Mode-Locked Lasers and Passive Cavities

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***Abstract*—We study interaction of well-separated localized structures of light in the presence of periodic perturbations. Oscillating localized structures were found to emit weakly decaying dispersive waves leading to a strong enhancement of the interaction and formation of new types of bound states. We discuss the applicability of our analytical results to the interpretation of experimental and numerical data reported earlier.**

Keywords—cavity solitons; ultrashort optical pulses; laser mode-locking; bound states of localized structures of light.

I. INTRODUCTION

Spatial and temporal cavity solitons (CSs) are, respectively, localized spots of light in transverse section of broad area laser systems and short optical pulses propagating along longitudinal axis of mode-locked lasers and coherently driven optical cavities. In particular, in [1] a formation and interactions of temporal CSs in a standard silica fiber cavity were studied experimentally. Here we present a theoretical study of the interaction of CS in the presence of periodic perturbations, caused by periodic modulations or self-pulsing instabilities.We show that these perturbations can lead to a drastic enhancement of CS interactions and formation of new types of CS bound states. In particular, the existence in mode-locked fiber lasers of bound states with rather large inter-soliton distances can be interpreted on the basis of our analysis.

II. INTERACTION OF CAVITY SOLITONS

Being well separated from one another CSs can interact via their exponentially decaying tails. Interference of these tails can produce an oscillating pattern responsible for the formation of CS bound states. Unlike most previous studies focused on the case of stationary CS interaction, in this presentation we analyze the interaction of CSs, which oscillate in time. Although the approach we use is general, to illustrate the enhancement of the CS interaction, we consider the two well known specific model equations. The first one is the Lugiato-Lefever model, which can be used to describe the optically driven fiber cavity studied experimentally in [1]. In this model the stationary CS can undergo an Andronov-Hopf bifurcation leading to undamped oscillations in time. The second model is the cubic-quintic complex Ginzburg-Landau equation (QCGLE) with the second order dispersion coefficient oscillating periodically in time. For both the models using an asymptotic approach we derive the interaction equations governing the slow time evolution of the oscillating CSs coordinates and phases [2]. It follows from these equations that the interaction strength is determined mostly by the rate of CS tail decay. For stationary CSs this decay rate is determined by a single exponent that dominates in the tail. On the contrary, for the CS oscillating in time at the frequency Ω, each harmonic frequency nΩ has its own spatial decay rate, which can be much slower than that of the stationary component. Thus, the oscillating CS tails can be viewed as being composed of slowly decaying dispersive waves, which result in a drastic enhancement of the CS interaction strength. Such kind of enhancement can be responsible for the appearance of CS bound states with very large CS separations (> 5 pulse width [3]) in mode-locked fiber lasers. Furthermore, using our results on QCGLE the appearance of bound states with phase difference close but not equal to $\pm\pi/2$ [4] can be explained and the possibility of the efficient control of the CS interaction can be demonstrated.

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