Strong enhancement of interaction of optical pulses induced by oscillatory instability

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Short optical pulses have numerous applications including high bit rate communications, optical tomography, spectroscopic measurements, material processing, frequency standards, etc. In relation to applications of temporal and spatial localized structures of light for all-optical information transmission, storage, and processing, the problem of interaction those structures is of particular importance. On one hand, interaction of optical pulses implies strict limitations on the amount of information that can be transmitted using a sequence of closely packed pulses. On the other hand, different bound states of localized structures of light arising as a result of their interaction could serve as an "alphabet" useful for increasing the amount of encoded information.

In this presentation, interaction of stationary and pulsating localized structures of light in active and passive optical devices is studied analytically and numerically. Being close enough to each other, optical pulses interact via decaying tails. Interference between the tails can produce intensity oscillations responsible for the formation of pulse bound states [1,2]. Using an asymptotic approach we derive and analyze a set of ordinary differential equations governing the slow time evolution of the parameters of individual pulses, such as their coordinates, optical and oscillation phases. Being independent of specific details of the model, the form of these "interaction equations" is determined mainly by the asymptotic behavior of the pulse tails and the symmetries of the model equations. They have a universal nature and can be used to study interaction of temporal or spatial localized structures not only in optical, but also in hydrodynamic, plasma, and even biological systems.

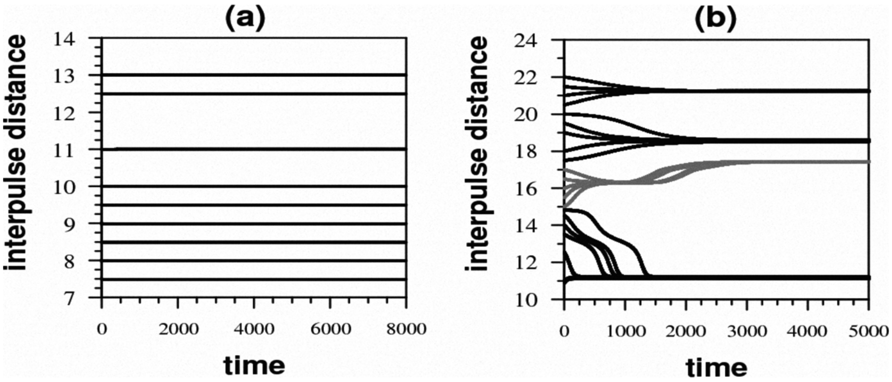

Fig. 1 Time dependencies of the distances between two interacting pulses in a driven Kerr cavity. Different lines correspond to different values of initial pulse spacings. (a) – Interaction of stationary pulses below Andronov-Hopf bifurcation threshold. Interaction strength of stationary pulses is negligible for the parameter values and initial spacings used in our numerical simulations. (b) – Formation of in-phase (black) and $\pi/2$-out-of-phase (grey) bound states of oscillating pulses due to enhancement of pulse interaction strength above Andronov-Hopf bifurcation threshold.

The stability properties of pulse bound states and the effect of symmetry breaking in the model equations are discussed. It is demonstrated that the break up of the phase shift symmetry due to small external injection into a mode-locked laser cavity can induce an instability leading to a transformation of stationary bound states into dynamic ones. These states are characterized by pulse coordinates and phases evolving periodically, quasiperiodically, or even chaotically in time.

Pulse interaction above the Andronov-Hopf bifurcation threshold leading to undamped oscillations of the individual pulse characteristics is investigated. We present numerical and analytical evidence that such kind of bifurcation can change drastically the character of pulse interaction. In particular, we demonstrate a very strong enhancement of the pulse interaction strength just above self-pulsing instability threshold in a driven Kerr cavity (see Fig. 1). This enhancement results in the formation of various new types of pulse bound states. We show that similar enhancement of pulse interaction strength takes place in optical devices with longitudinal modulation of the refractive index (dispersion management).

References

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