Synchronization of Interacting Temporal Cavity Oscillons

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Temporal cavity solitons (TCS) – localized dissipative structures of light propagating along the longitudinal axis of coherently driven optical cavities – are very promising for applications in telecommunication technology. In a recent work [1] formation and interactions of TCS in a standard silica fiber cavity were studied experimentally. Here we present a theoretical investigation of the interaction of the TCS within the framework of the Lugiato-Lefever (LL) model. Major attention is given to the interaction of oscillating solitons above a self-pulsing instability threshold and to the effect of external periodic modulations on the soliton interactions.

Being well separated from one another dissipative optical solitons interact via their exponentially decaying tails. Interference of those tails can produce an oscillating pattern responsible for the formation of soliton bound states. Most of the previous studies on soliton interaction were focused on the case of stationary or uniformly moving solitons. On the other hand, the soliton itself can exhibit instabilities leading to various dynamical regimes. One of the most important and frequently encountered between them is the Andronov-Hopf bifurcation which leads to undamped pulsations of the soliton's parameters, such as amplitude, width, etc. Such kind of oscillating localized solutions are usually called oscillons. In this presentation we develop a general theory of a weak interaction of two well separated optical oscillons. We derive a set of interaction equations governing slow time evolution of the time spacing τ and oscillations phase difference ϕ of two interacting temporal cavity oscillons

$$\frac{d\tau}{dt} = \sum_{n=-\infty}^{n=\infty} B_n e^{-\alpha_n y} \sin(\beta_n \tau + \Theta_{1n})\cos(n\tau), \quad \frac{d\phi}{dt} = \sum_{n=-\infty}^{n=\infty} B_n e^{-\alpha_n y} \cos(\beta_n \tau + \Theta_{2n})\sin(n\phi), \tag{1}$$

and present the results of direct numerical simulations of the model equation which are in a good agreement with the theoretical predictions.

We show that although the interaction of stationary TCS is very weak, above the Andronov-Hopf bifurcation the oscillating solitons start to radiate weakly decaying waves (see Fig. 1, left panel) and, as a result, their interaction becomes drastically enhanced. This leads to a formation of new types of soliton bound states observable in experiment. Different bound states of oscillons are characterized by different distances τ between them and the oscillation phase differences ϕ, i.e., correspond to different oscillon synchronization regimes. An interpretation of the results of numerical simulations based on the analytical analysis of the interaction equations is given. We have found that a phenomenon of "subharmonic" synchronization, which corresponds to the case when the terms with $n>1$ dominate in Eqs. (1), is typical of this situation. Furthermore, we demonstrate a possibility to control the interaction of dissipative solitons by applying a weak external periodic modulation to the quintic complex Ginzburg-Landau equation (QCGLE), see Fig. 1, right panel.

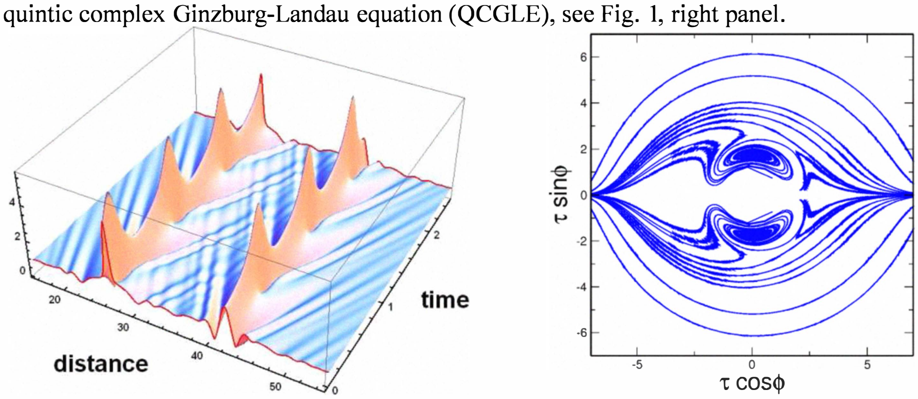

Fig. 1 Left: Bound state of oscillating TCS: numerical integration of the LL model. Right: Interaction of dissipative solitons in the presence of periodically modulated dispersion: phase portrait obtained by direct numerical integration of the QCGLE. τ is the distance and ϕ is the phase difference of the solitons.

References

[1] F. Leo, S. Coen, P. Kockaert, S.-P. Gorza, P. Emplit, and M. Haelterman, " Temporal cavity solitons in one-dimensional Kerr media as bits in an all-optical buffer, " Nat. Photon., **4**, 471–476 (2010).