Few-cycle optical solitons in linearly coupled waveguides

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I. INTRODUCTION : We consider the coupling of two optical waveguides in the few-cycle regime. The analysis is performed in the frame of a generalized Kadomtsev-Petviashvili model. A set of two coupled modified Korteweg–de Vries equations has been derived: three types of coupling can occur,involving the linear index, the dispersion, or the nonlinearity. The linear nondispersive coupling is investigated numerically, showing the formation of vectorsolitons. Separate pulses may be trapped together if they have not initially the same location, size, or phase, and even if their initial frequencies differ.

II. LINEAR COUPLING: We solve the model in dimensionless form, assuming a purely linear and nondispersive coupling, namely :

$$\partial_z u = -\partial_t(u^3) - \partial_t^3 u - C\partial_t v$$
$$\partial_z v = -\partial_t(v^3) - \partial_t^3 v - C\partial_t u$$

using a standard fourth-order Runge-Kutta scheme in the Fourier domain. The initial data are :

$$u = A_u sin(\omega_u t + \varphi_u) e^{-(t-t_u)^2/\tau_u^2}$$
$$v = A_v sin(\omega_v t + \varphi_v) e^{-(t-t_v)^2/\tau_v^2}$$

II.1 Different Amplitudes

A soliton is launched in channel u, *and a* smaller input with same duration in channel v.

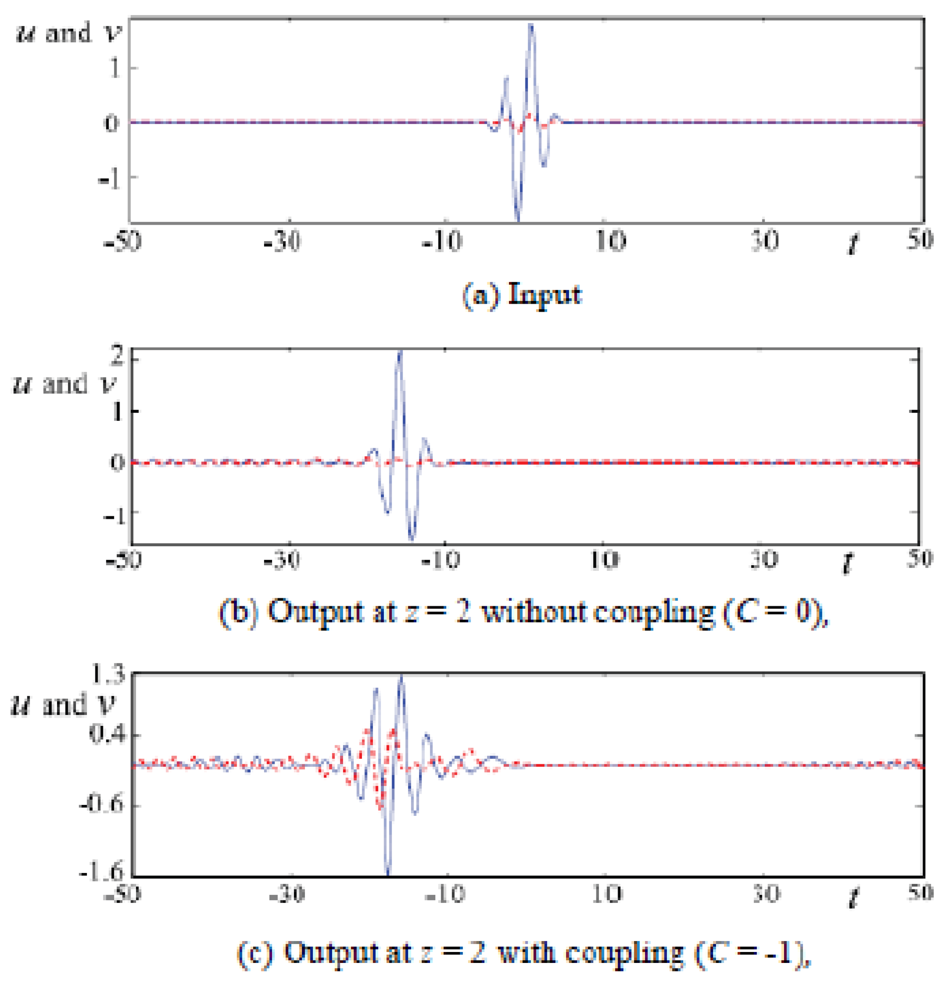

FIG.1. Solid blue line : u, dashed red line : v. Parameters :$A_u = 2$, $A_v = 0.2$, $\lambda_u = \lambda_v = 1$, $FWHM_u = FWHM_v = 3$, $\varphi_u = \varphi_v = 0$, $t_u = t_v = 0$

- Without coupling: *u forms a soliton, v is spread out by dispersion.*
- With coupling: a vector soliton forms, which involves localized intensity on both channels. Energy is transferred from one channel to the other.

II.2 Mutual trapping

The mutual trapping of the two solitons can occur even if their centers do not coincide exactly at the beginning of the process. An example is shown in Fig. 2: the two input pulses are identical, but shifted along t

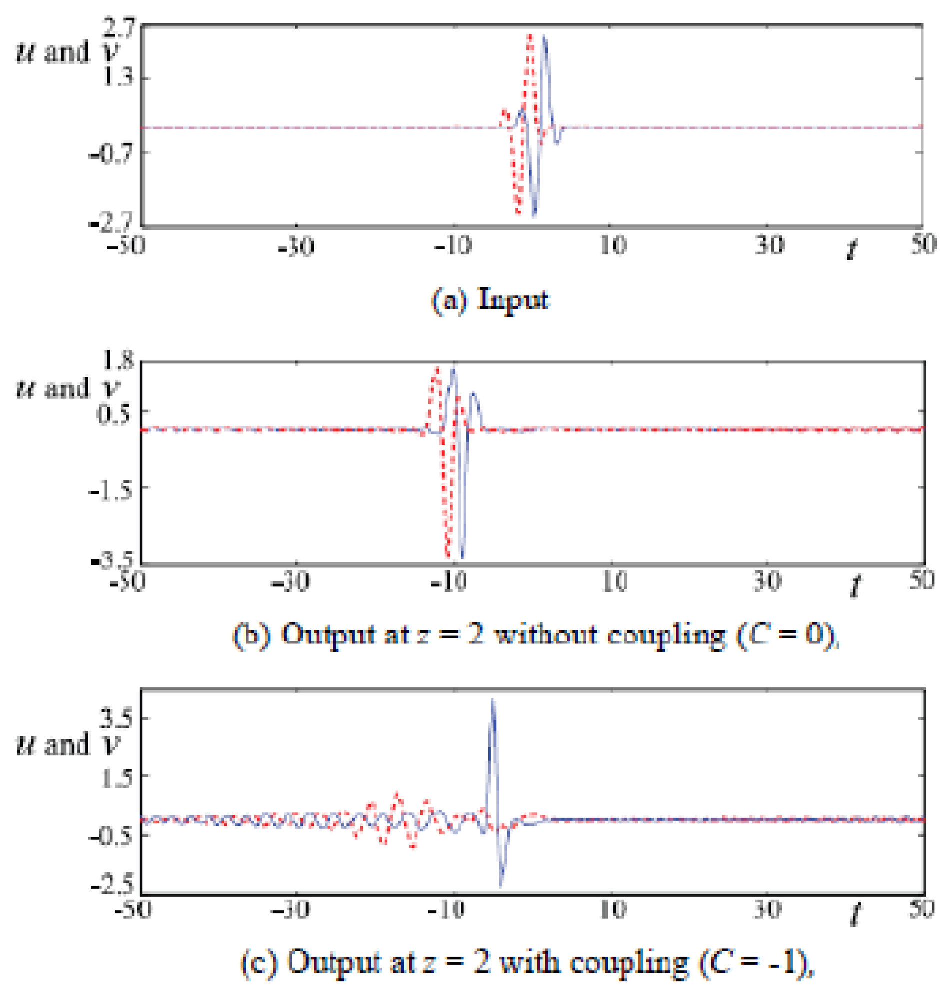

FIG.2. Solid blue line : u, dashed red line : v. Parameters :$A_u = A_v = 3$, $\lambda_u = \lambda_v = 1$, $FWHM_u = FWHM_v = 2$, $\varphi_u = \varphi_v = 0$, $t_u = 1$, $t_v = -1$

- Without coupling: *u and v propagate as two* identical solitons shifted in position
- With coupling: they form a single vector soliton, whose intensity mostly propagates in the *u channel, plus some radiation.*

II.3 Solitons with different frequencies

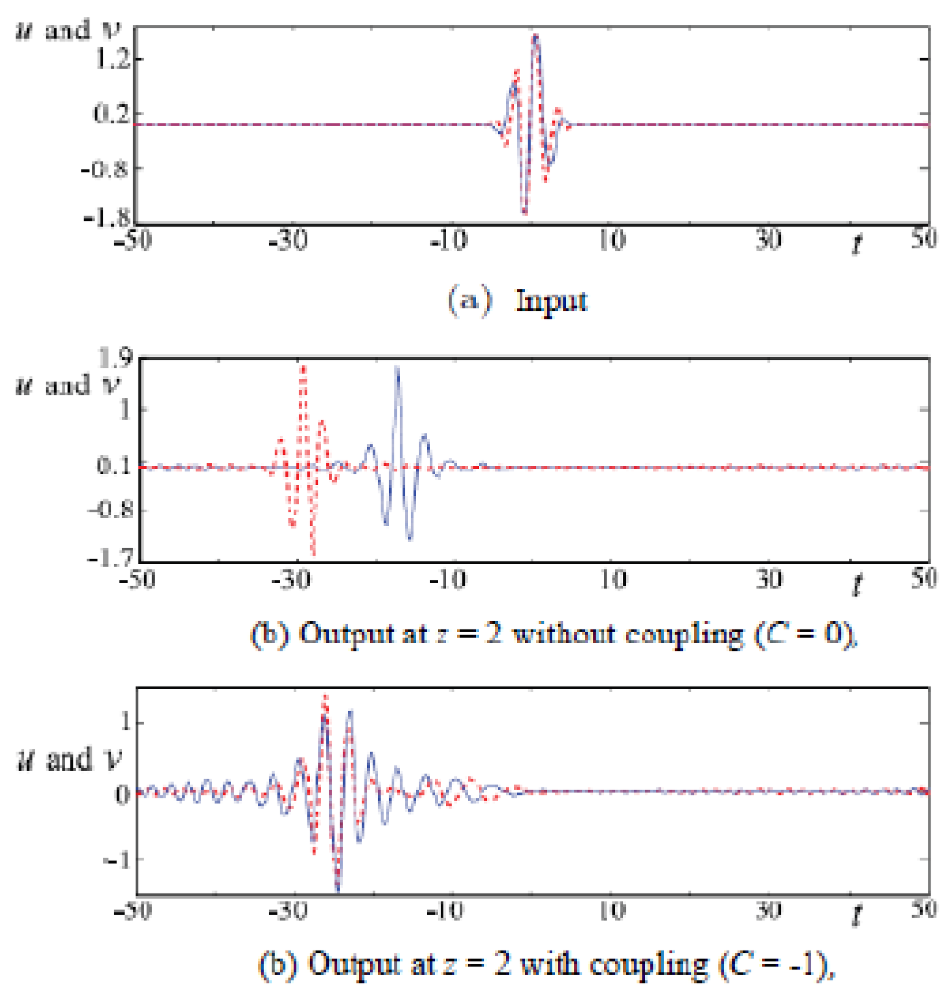

FIG.3. Solid blue line : u, dashed red line : v. Parameters :$A_u = A_v = 1.8$, $\lambda_u = 1$, $\lambda_v = 0.8$, $FWHM_u = FWHM_v = 3$, $\varphi_u = \varphi_v = 0$, $t_u = t_v = 0$

Two solitons with different frequencies can lock together to form a vector soliton.
- Without coupling: Due to dispersion, *u and v* have different velocities and separate
- With coupling: they merge into a single vector soliton.

II.4 Energy Evolution

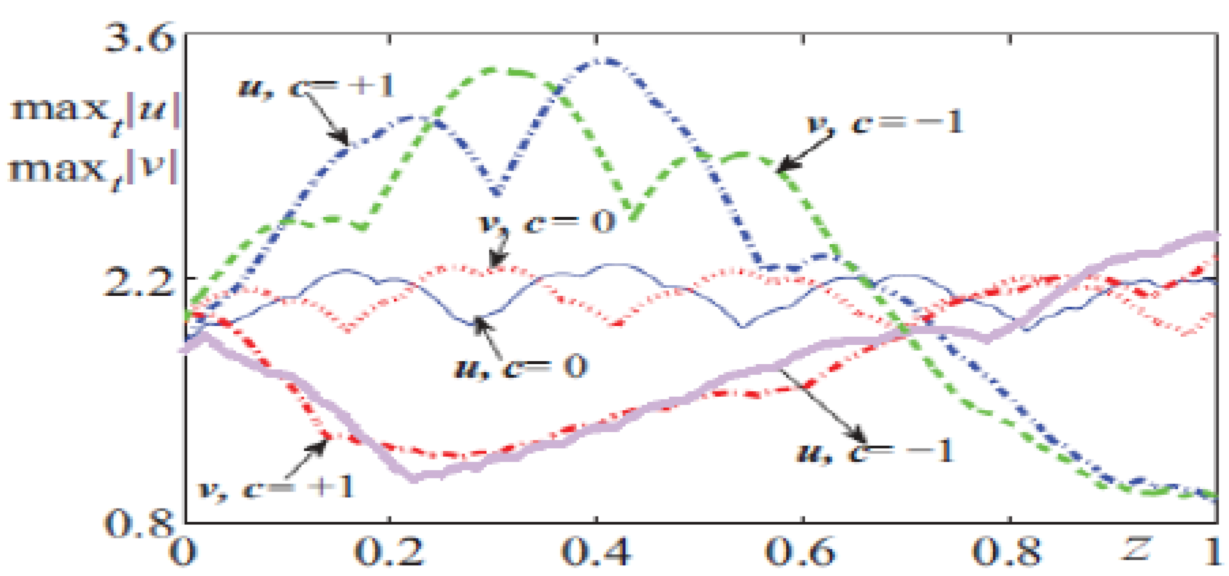

FIG. 4. Evolution of the amplitudes in both channels: plots of $\max_t|u|$, $\max_t|v|$ versus the propagation distance z. For C = +1, u grows and v decreases first; for C = −1, it is the contrary. The parameters are $A_u = A_v = 2$, $\lambda_u = \lambda_v = 1$, $FWHM_u = FWHM_v = 3$, $\varphi_u = 0$, $\varphi_v = \pi/2$, $t_u = t_v = 0$.

Some energy is transferred from one channel to the other. This energy exchange can occur periodically as in the case of monochromatic waves; It depends on the sign of the coupling.

III. CONCLUSION

We considered the coupling of two optical waveguides, in which few-cycle pulses are launched. Starting from a simplified model of two coupled modified Korteweg–de Vries equations which describe the nonlinear propagation in the coupled waveguides.
We investigated numerically the evolution of two input few-cycle pulses in the presence of a linear nondispersive coupling. The formation of vector solitons is evidenced.
Separate pulses can be mutually trapped, with initial mismatch in location, size, or phase, and even if their initial frequencies differ.

Reference : H. Leblond, and S. Terniche, Phys. Rev. A 93, 043839 (2016)