Nonlinear Optical Engineering

Optical Solitons (2)
(NFO 5th ed: 5.2 ~ 5.3)

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Fiber Solitons (2)

Fundamental soliton:

Shape-preserving solution: $\rightarrow u(\xi,\tau) = V(\tau)\exp[i\phi(\xi,\tau)]$

NLSE: $\rightarrow\ i\frac{\partial u}{\partial \xi} + \frac{1}{2}\frac{\partial^2 u}{\partial \tau^2} + |u|^2 u = 0$

$$\rightarrow \phi(\xi,\tau) = K\xi - \delta\tau$$

$$\rightarrow \frac{d^2V}{d\tau^2} = 2V(K - V^2) \qquad \leftarrow \times 2\frac{dV}{d\tau}$$

$$\rightarrow \left(\frac{dV}{d\tau}\right)^2 = 2KV^2 - V^4 + C$$

$$\leftarrow V = 1\ \&\ dV/d\tau = 0$$ ← At the soliton peak

$$\rightarrow K = \frac{1}{2}$$

$$\rightarrow V = \mathrm{sech}(\tau)$$

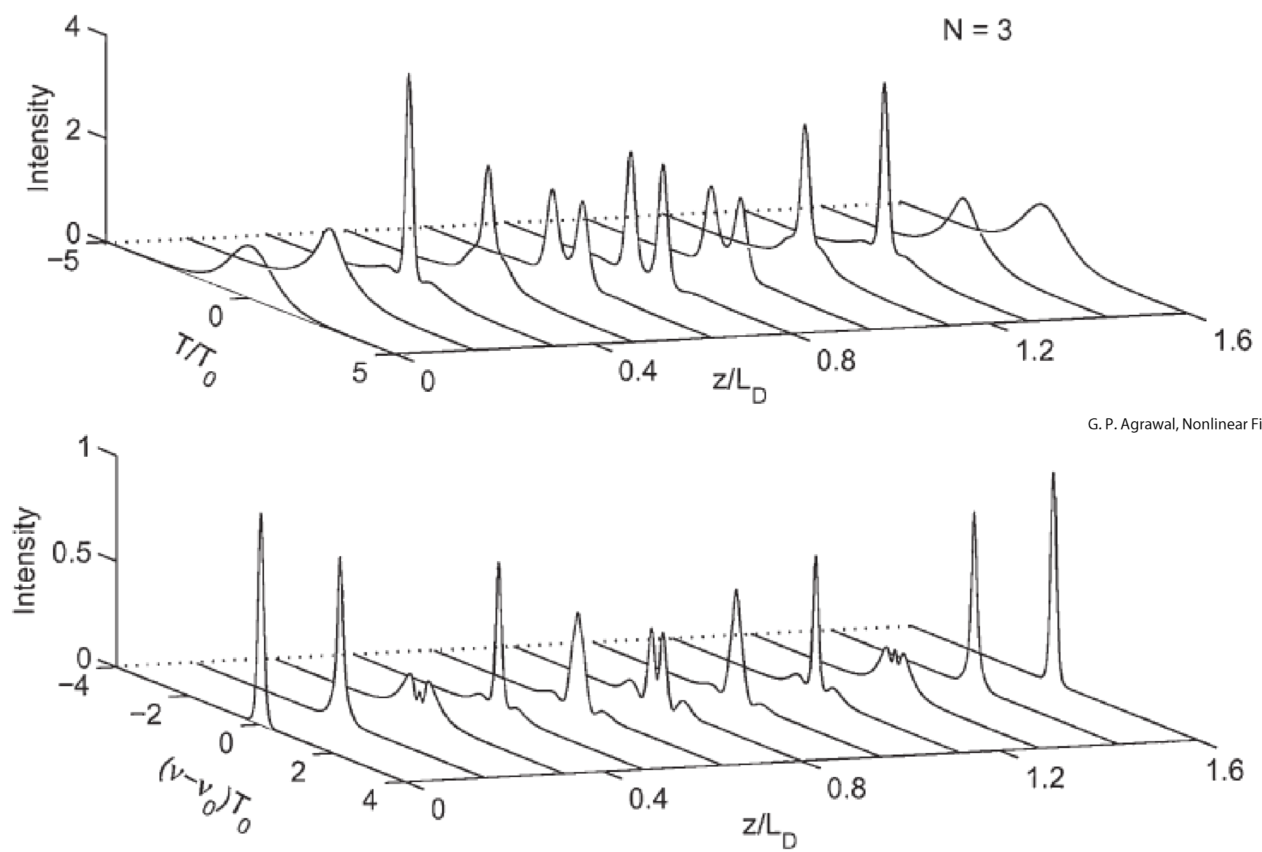
In result: $\rightarrow u(\xi,\tau) = \mathrm{sech}(\tau)\exp(i\xi/2)$

Fiber Solitons (3)

Higher-order solitons:

Periodically evolving solution: $\rightarrow N^2 = \frac{L_D}{L_{NL}} = \frac{\gamma P_0 T_0^2}{|\beta_2|}$

Third-order soliton:



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Fiber Solitons (4)

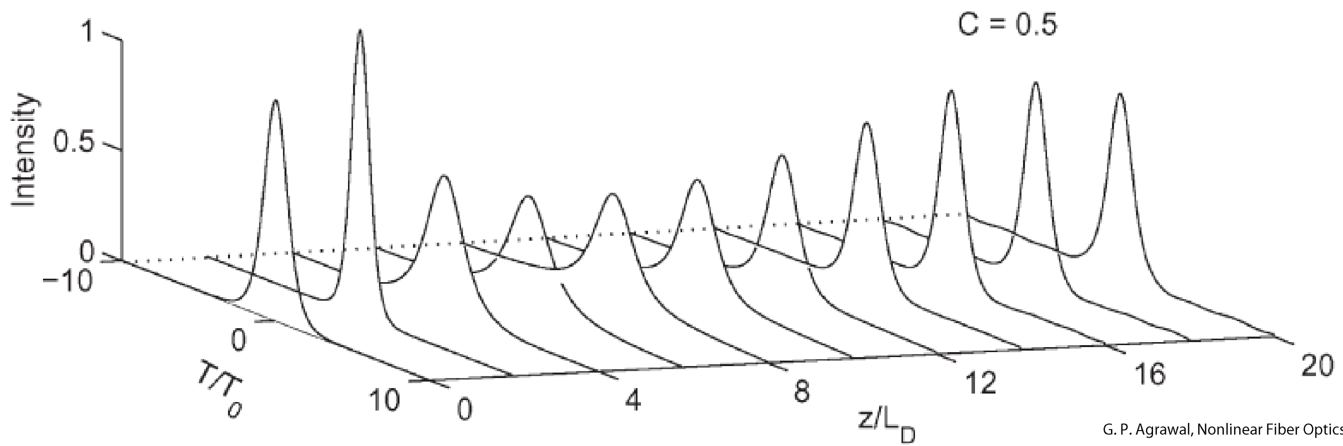
Soliton stability:

Perturbations: $\rightarrow u(0,\tau) = (\tilde{N} + 2\varepsilon)\text{sech}[(1 + 2\varepsilon / \tilde{N})\tau]$

$$\rightarrow u(0,\tau) = N\text{sech}(\tau)\exp(-iC\tau^2 / 2)$$

$\rightarrow$ Numerical analysis

Soliton formation in the presence of an initial linear chirp:



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$\leftarrow$ Pulse energy loss via forming dispersive waves

Other Types of Solitons (1)

Dark solitons:

NLSE: $\rightarrow\ i\dfrac{\partial u}{\partial \xi} - \dfrac{1}{2}\dfrac{\partial^2 u}{\partial \tau^2} + |u|^2 u = 0$ $\leftarrow$ In the normal GVD condition

General solution: $\rightarrow u(\xi,\tau) = \eta[B\tanh(\varsigma) - i\sqrt{1-B^2}\,]\exp(i\eta^2\xi)$

$\leftarrow \varsigma = \eta B(\tau - \tau_s - \eta B\sqrt{1-B^2}\,)$

$\leftarrow |B| < 1$ $\leftarrow$ Grey solitons

$\leftarrow |B| = 1$ $\leftarrow$ Black soliton

$\rightarrow u(\xi,\tau) = \tanh(\tau)\exp(i\xi)$

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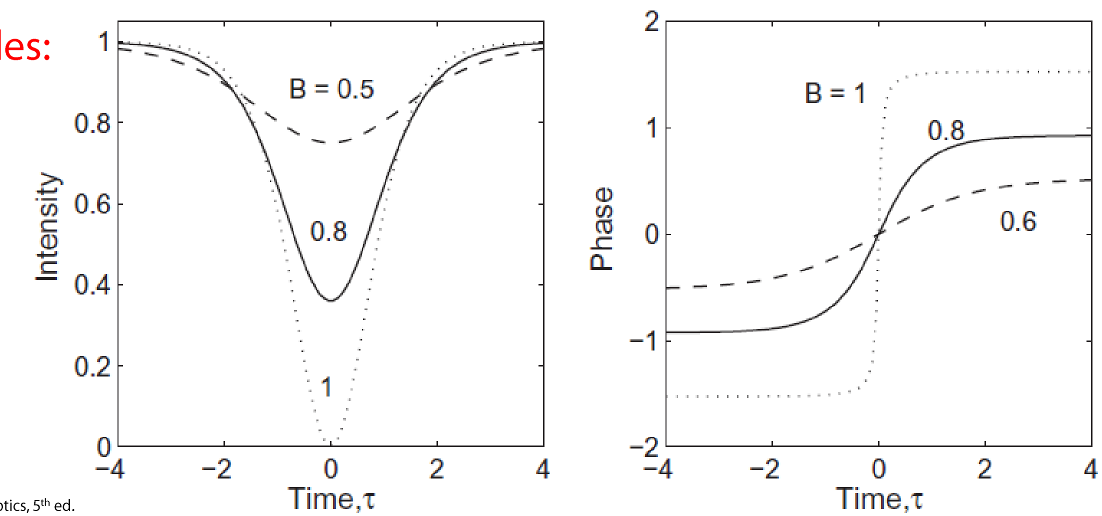
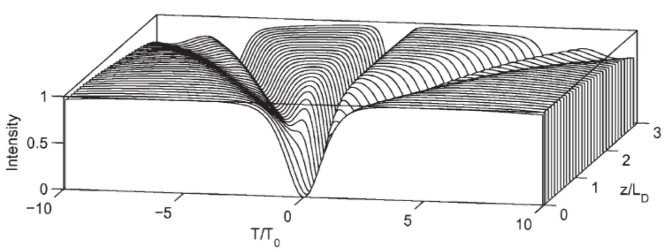
Intensity and phase profiles:



Third-order dark soliton:



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Other Types of Solitons (2)

Bistable solitons:

Intensity-dependent refractive index: $\rightarrow \tilde{n}(I) = n + n_2 I \quad \rightarrow \tilde{n}(I) = n + n_2 f(I)$

$\leftarrow$ "Saturation" considered

NLSE: $\rightarrow i\dfrac{\partial u}{\partial \xi} + \dfrac{1}{2}\dfrac{\partial^2 u}{\partial \tau^2} + f(|u|^2)u = 0$

$$\rightarrow u(\xi,\tau) = V(\tau)\exp(iK\xi)$$

$$\rightarrow \frac{d^2V}{d\tau^2} = 2V[K - f(V^2)] \quad \rightarrow \left(\frac{dV}{d\tau}\right)^2 = 4\int_0^V [K - f(V^2)]VdV$$

$$\rightarrow 2\tau = \int_0^V \left(\int_0^{V^2} [K - f(P)]dP \right)^{-1/2} dV$$

Soliton energy: $\rightarrow E_S(K) = \dfrac{1}{2}\displaystyle\int_0^{P_m} [K - F(P)]^{-1/2} dP \quad \leftarrow F(P) = \dfrac{1}{P}\displaystyle\int_0^P f(P)dP$

$\leftarrow F(0) = 0$

$\leftarrow P_m$: the smallest positive root of $F(P) = K$

Bistable soliton solutions: $\leftarrow K$ & P_m

Other Types of Solitons (3)

Dispersion-managed solitons:

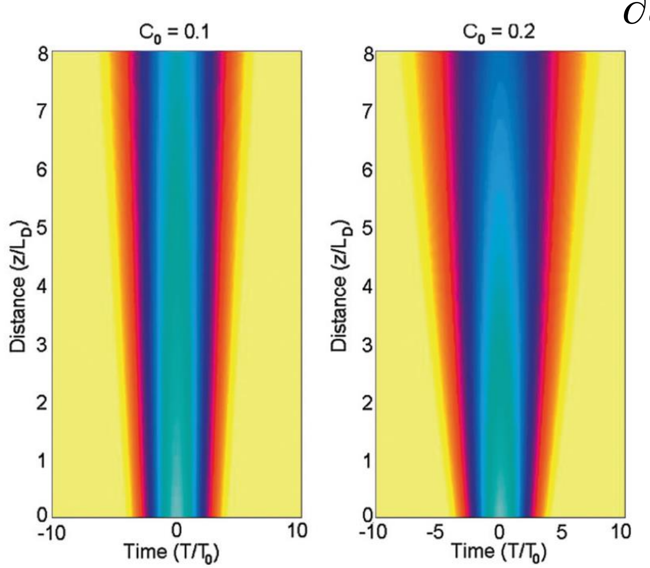
NLSE: $$\rightarrow i\frac{\partial u}{\partial \xi}+\frac{d(\xi)}{2}\frac{\partial^2 u}{\partial \tau^2}+|u|^2 u=0$$

Optical similaritons:

NLSE: $$\rightarrow i\frac{\partial A}{\partial z}-\frac{\beta_2(z)}{2}\frac{\partial^2 A}{\partial T^2}+\gamma(z)|A|^2 A=i\frac{g(z)}{2}A$$

Compatibility condition: $$\rightarrow g(z)=C(z)\frac{\beta_2(z)}{T_0^2}+\frac{d}{dz}\ln\left[\frac{\beta_2(z)}{\gamma(z)}\right]$$

$$\rightarrow i\frac{\partial U}{\partial \varsigma}-\mathrm{sgn}(\beta_2)\frac{1}{2}\frac{\partial^2 U}{\partial \chi}+|U|^2 U=0$$



→ Self-similar transformation into a chirped parabolic-shape pulse

→ Good for forming a high-energy ultra-short pulse

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