A novel model of Cross Phase Modulation in WDM optical systems

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Abstract
We propose a novel model for the evaluation of intensity and phase distortion due to XPM in WDM optical systems. The XPM effect is modeled as a perturbing term multiplying the undistorted signal.

Motivation
• XPM is the main performance limiting phenomenon for long-haul high-capacity WDM systems
• Simulation of Nonlinear Schroedinger equation based on the Split-Step method is not a viable approach: highly time consuming, allows only to study few realizations and does not separate different effects
• Previously proposed models, based on pump and probe approach, can not be extended to the practical case of a modulated probe.

Math
Starting point: the Nonlinear Schroedinger equation
\[
\frac{\partial a_i(z,t)}{\partial t} = -i\alpha_i(z,t) + \frac{1}{2} j \beta_{zz} \frac{\partial^2 a_i(z,t)}{\partial z^2} - j \gamma \sum_{k=1}^{N_{\text{ch}}} |a_k(z,t)|^2 a_i(z,t)
\]

The innovative assumption:
XPM perturbation is a multiplicative factor

\[ a_i(z,t) = a_{i0}(z,t) \cdot \rho(z,t) \]

\[
\frac{\partial \rho(z,t)}{\partial t} = \frac{1}{2} j \beta_{zz} \frac{\partial^2 \rho(z,t)}{\partial z^2} - 2 j \gamma \sum_{k=1,k\neq i}^{N_{\text{ch}}} |a_k(z,t)|^2 \rho(z,t) + j \beta_{z} \left[ \frac{1}{a_{i0}(z,t)} \frac{\partial a_{i0}(z,t)}{\partial t} \frac{\partial \rho(z,t)}{\partial t} \right]
\]

\[
\frac{\partial \rho(z,t)}{\partial z} = \frac{1}{2} j \beta_{zz} \frac{\partial^2 \rho(z,t)}{\partial z^2} - 2 j \gamma \sum_{k=1,k\neq i}^{N_{\text{ch}}} |a_k(z,t)|^2 \rho(z,t)
\]

Method
• Evaluation of \( a_{i0}(L,t) \) using standard Split-Step method
  • Single channel simulation: very fast
• Evaluation of \( \rho(z,t) \) by mean of the new derived equation
• Calculation of \( a(L,t) \)
• Eventually: Monte-Carlo study over thousands of realizations in order to statistically characterize the XPM perturbation

Validation
• WDM system: 9 channels @ 10 Gbit/s, \( \Delta f=100 \) GHz
• 100 km of NZDSF fiber (\( \beta_2=-5.74 \) ps²/km, \( \gamma=1.84 \) W⁻¹ km⁻¹)
• Transmitted power: 0 dBm per channel

Plots and Histograms