Project: Noise simulations of the soliton

GOALS

1. To use Monte Carlo simulations to understand the effect of noise on classical soliton propagation.
2. To understand the limitations on soliton propagation due to noise.

REFERENCES

1. J. P. Gordon and H. A. Haus, "Random walk of coherently amplified solitons in optical fiber transmission," Opt. Lett. **11** (10), pp. 665–667, 1986.
2. H. A. Haus, "Quantum noise in a solitonlike repeater system," J. Opt. Soc. Am. B **8** (5), pp. 1122–1126, 1991.
3. T. Georges, "Perturbation theory for the assessment of soliton transmission control," Opt. Fiber Technol. **1** (2), pp. 97–116, 1995.

PROCEDURE

The nonlinear Schrödinger equation is given by

$$i\frac{\partial u}{\partial z} + \frac{\beta_2}{2}\frac{\partial^2 u}{\partial t^2} + \gamma |u|^2 u = 0. \tag{1}$$

1. For the case $\beta_2 < 0$, verify that the solution has the functional form

$$u(z,t) = A \operatorname{sech} Bt e^{i\phi z}, \tag{2}$$

   by substitution. What is the relationship between A and B and between A and ϕ? Show your work.

2. Simulate the above solution in OCS and verify that its envelope and power spectrum remain constant over long distances. Show plots of your simulations for the amplitude and real part of u as well as the power spectrum. Use $\beta_2 = -20$ ps^2/km and $\gamma = 2 \times 10^{-20}$ W^{-1}km^{-1}. What pulse width and peak power should you choose?

3. Add 0.25 dB/km loss in the fiber and periodic amplification in the line, which for now should be just gain with no noise. Try out different spacings of the amplifiers: 10, 20, 40, and 80 km. What is the effect of these spacings on the pulse after 8,000 km? Compare your numerical solution with the exact solution derived in part 1. What is the error in both amplitude and phase? How does it vary with amplitude spacing?

4. Add noise to the signal in the amplifiers. For different noise realizations, compute the mean time and amplitude shift of the pulse due to the added noise. How much does it vary?

5. Compare eye diagrams for a 32-bit PRBS after 320 km for various choices of amplifer noise figure. Then, fix the noise figure at each amplifier and compare the result at 320 km with 640 km and 1280 km. What is the predominant effect — timing jitter or amplitude jitter?

6. Run a Monte Carlo simulation with 100,000 noise realizations and plot the probability density functions for the timing jitter and the amplitude jitter for the propagation in the previous part. What are the shapes? How does the mean frequency of the final pulse vary from its initial value for various noise realizations? What is the pdf?

7. Read the 1986 paper by Gordon and Haus. In this paper, the authors predict a maximum distance over which classical solitons are viable for communication when only amplifier noise is considered. Can you reproduce this analytical result in your simulations?