Phase Sensitive Amplifiers for Ultra-long Distance Soliton Propagation

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Lumped erbium-doped fiber amplifiers have been demonstrated as effective devices for compensating loss in long-distance soliton communication systems.[1] More recently, various filtering schemes[2] have been proposed as a way of reducing the Gordon-Haus jitter[3] present in such systems, thereby increasing the maximum allowable bit-rate distance product. As a possible alternative to erbium-doped amplifiers, the use of lumped phase-sensitive parametric amplifiers has been proposed.[4] A chain of such amplifiers should lead to a higher bit-rate-distance product because no spontaneous emission noise is present.[4]

We have presented a theoretical analysis of pulse evolution in a nonlinear optical fiber where loss is compensated by a chain of periodically-spaced phase-sensitive parametric amplifiers.[5] By averaging over the rapid oscillations induced by the loss and periodic amplification (in a manner similar to that done for erbium-doped amplifiers[1]) we have obtained a fourth-order diffusion equation that describes the pulse evolution. The derivation shows that, in contrast to the erbium-doped amplifier case, no pulse evolution occurs on the length-scale of the soliton period; it is only over much longer length-scales that appreciable pulse evolution occurs.

In addition, analytical and numerical studies of the pulse evolution equation show that these pulses behave quite differently from pulse solutions of the nonlinear Schrödinger (NLS) equation. In particular, we have shown that for a wide range of parameters the steady-state solutions of the evolution equation are stable, as shown in Figure 1. As a result, a pulse that is initially not of the proper amplitude or width asymptotically approaches the steadystate solution without shedding dispersive radiation, as would occur for a solution of the NLS equation.

The analysis also provides a physical explanation for these results. After propagation through a segment of the fiber, the pulse is attenuated by the loss and develops a quadratic phase sweep across its profile since group-velocity dispersion and self-phase modulation do not exactly cancel one another as the pulse decays. The phase-sensitive parametric amplifiers, however, work to produce an output pulse that is uniform in phase; the phase sweep induced in the pulse is therefore attenuated by the amplifiers, cancelling the effect of the dispersion. Thus, the amplifiers act as phase-sensitive filters (analogous to lock-in amplifiers) that fight dispersion. In addition, since this effect does not depend on self-phase modulation being present, we have recently proposed using phase-sensitive amplifiers to compensate dispersion in linear fiber optic communication systems.[6]

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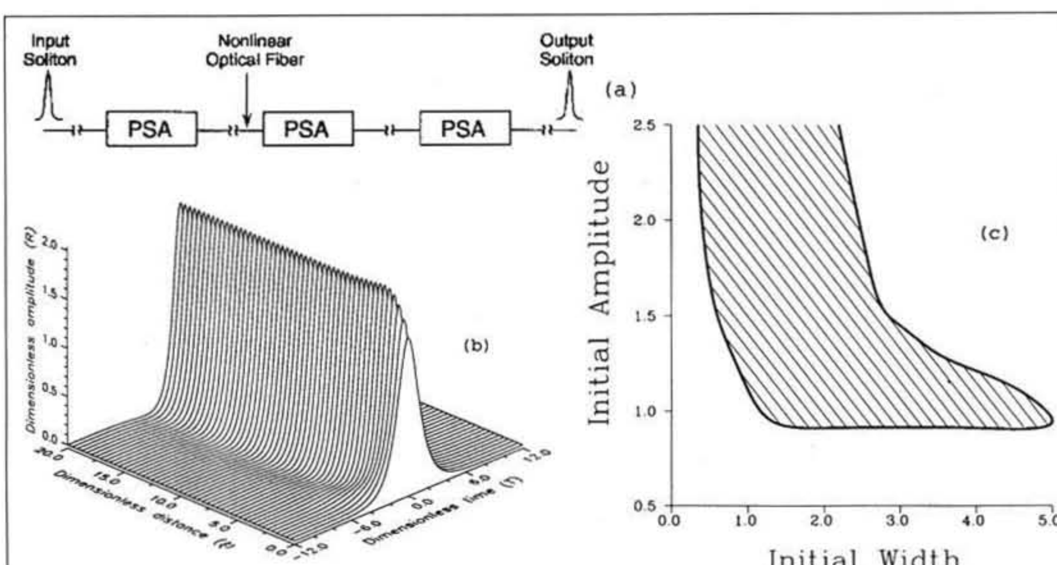

Figure 1(a). Schematic of a nonlinear optical fiber transmission line in which loss is balanced by a chain of phase-sensitive parametric amplifiers. **(b)** An example of stable pulse propagation, assuming a fiber loss of 0.24 dB/km, an amplifier spacing of 36.2 km, a soliton period of 450 km, and a gain of 8.7 dB at each amplifier. The pulse envelopes are plotted after every 235 amplifiers. **(c)** Stability region (shaded area) for the parameters used in (b).