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Stability of periodically amplified solitons in the non-periodical dispersion varying system

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We present numerically simulated results on stabilities of optical soliton transmission in highly-dispersion-perturbed optical fiber systems. We have found that the perturbation of dispersion along the transmission line does not significantly degrade stability of soliton transmission as long as the average soliton concept is obeyed.

The growth rate of data and telecommunication services such as E-mail, internet, tele-banking and new broadband services, such as video conferencing, video on demand and other multimedia services, are now spurring the need for higher capacities for lightwave transmission systems [1]. To provide such high capacity services it is necessary to deploy optical fiber networks based on fiber to the curb (FTTC) or fiber to the home (FTTH) systems. In the terrestrial networks, the systems inevitably installed by various providers are spliced with various types of optical fibers which induce variations of dispersion and nonlinearity. Even though the installed fibers follow international standards it is expected that there exist perturbations of dispersion along the transmission line. In this Letter, we study the system performance of soliton transmission through numerical simulation in the highly dispersion perturbed system. Particularly we examine the stability of initial pulse widths and amplitude in soliton transmission.

Our letter is based on numerical integration of the nonlinear Schrödinger equation using the dispersion profiles obtained by a random number generation. We expect that perturbation of dispersion parameters along the fibers influences the pulse widths and the peak amplitude. If we consider the case where the dispersion of the fibers is locally and highly varied along the transmission line, the nonlinear Schrödinger equation is modified as follows [3],

$$i\frac{\partial u}{\partial Z} + \frac{1}{2}d(Z)\frac{\partial^2 u}{\partial \tau^2} + |u|^2 u = -i\Gamma u + iG(Z)u \qquad (1)$$

where the time τ is normalized to the characteristic time $\tau_0 = \tau_s/1.76$ where τ_s is the soliton full width at half maximum. The distance Z is normalized to the dispersion distance $L_D = \frac{2\pi c \tau_s^2}{(1.76\lambda)^2|D|}$ which is expressed in terms of the group dispersion parameter D[ps/nm·km]. c is the speed of light. The normalized loss rate is $\Gamma = \alpha L_D$ where α is the loss rate per unit length of the fiber. The gain of periodically lumped amplifiers G(Z) with an amplifying spacing normalized to the dispersion distance follows rules of the averaged soliton concept given by Hasegawa [4]. d(Z) represents a functional variation of the group velocity dispersion from the average dispersion along the length of fiber and is given by $d(Z) = \frac{D(Z)}{<D>}$ where $< D >$ is the average dispersion.

To examine the dependence of soliton transmission on random dispersion perturbations, a simple point-to-point transmission line shown in Fig. 1 is numericall-considered by means of the split step Fourier method [2]. This transmission line comprised equal lengths of fibers of randomly varied dispersion. In all the presented examples the total length of fiber was 340 km, and the path average dispersion was D = +1.0 ps/nm·km. In our simulation the optical fiber loss was

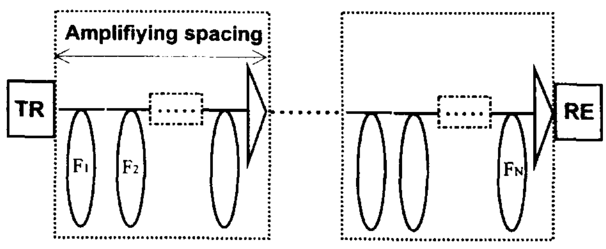

FIG. 1. The point-to-point transmission line consists of optical fibers with various dispersions.

assumed to be 0.2 dB/km. To simplify the problem we kept the nonlinear coefficient constant along the transmission line and assumed high order dispersions to be negligible. An input signal was considered to be a typical soliton pulse of sech type with pulse width of 13 ps which is corresponding to a 10 Gbps RZ signal. For these parameters the dispersion length is 42 km and the soliton length is z_0 = 65 km. The path average regime applies only where reshaping of the solitons is negligible between consecutive amplifier stages [3,4]. For this reason, the amplifier spacing was set to be approximately 40 km and the normalized input peak amplitude was set to be 1.523 to compensate the excessive fiber loss occurring just before the amplifier.

We have observed the behavior of quasi-stable solitons in such highly dispersion perturbed systems. The representative profiles of the dispersion given in Fig. 2. composed of unit cells of 4 km long fiber with the dispersion parameters varying between the upper limit of +1.5 ps/nm·km and the lower limit of 0.5 ps/nm·km. Fig. 3 shows intensity profiles at the end of each unit

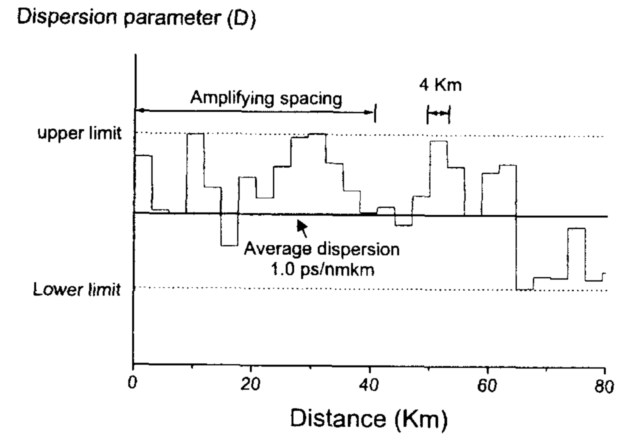

FIG. 2. Typical dispersion profiles used in calculation. The upper and lower limits were 1.5 ps/nm·km and 0.5 ps/nm·km respectively.

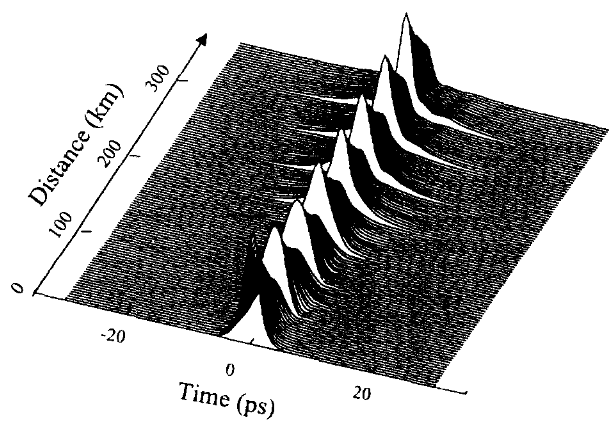

FIG. 3. Soliton transmission with the dispersion perturbation

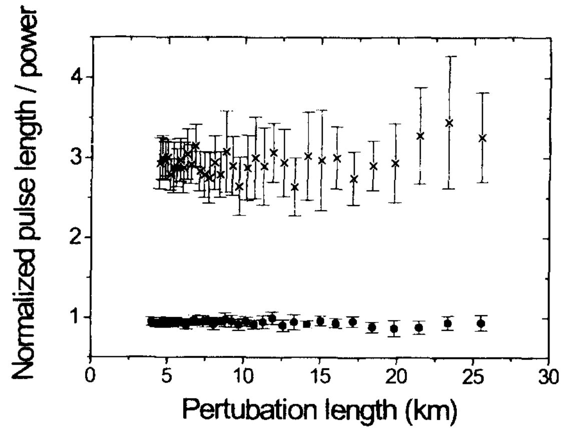

FIG. 4. Dependence of pulse length and peak intensity on variation of perturbation length (×: pulse length, •: peak intensity).

cell. In this case, the soliton shape was not significantly modified over the transmission distance. But we observed the scattering of energy from the soliton into the radiative waves, as seen in the dispersion alternating system studied for dispersion management [5]. Physically such radiation is attributed to a local mismatch of the nonlinearity and dispersion caused by the fiber loss and the dispersion perturbations.

We investigated the variation of the pulse lengths and the peak amplitudes of the input pulse as function of the change of the perturbation length after transmission of a 340 km long fiber. Fig. 4 shows variation of the pulse lengths and the peak amplitudes of the input pulse when the perturbation length is varied from 4 km to 26 km. The increase of the perturbation length does not significantly increase the pulse length and the original shape of the initial soliton is preserved. However it causes a slight reduction of the peak amplitude. The results showed that a stable transmission of the soliton is possible in dispersion perturbed systems as long as an initial peak power adequate for the calculated average dispersion is launched into the transmission line. It should also be noted that when the perturbation is increased, there is a transformation from the hyperbolic sech type soliton to a gaussian shape pulse. This was checked by the time-bandwidth product which is 0.315 for a soliton and 0.44 for a gaussian shape pulse. We found that there was a transition of the time-bandwidth product value from 0.315 to 0.41 after propagation of 340 km. Finally we have found that the average soliton concept is strictly applicable to this system. For the amplifying spacing longer than the soliton period, a rapid fluctuation of pulse length and peak amplitude was observed. As an example, for an amplifier spacing of 80 km the pulse length becomes twice that for the case of amplifier spacing of 40 km.

In conclusion we have examined the stability of optical soliton propagation in highly dispersion perturbed transmission systems. As in dispersion managed soliton systems we have confirmed three constraints which must be applied to maintain a stable soliton transmission. First, the path average dispersion must be anomalous, which is necessary to formation of a soliton. Second is that the perturbation length should be sufficiently short compared to the dispersion length of the system. Finally, the magnitude of the dispersion perturbation should not be significantly high otherwise the soliton energy is rapidly coupleout from the pulse into radiative waves.

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