The Some Study of Optical Soliton Transmission with Lumped Amplification

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Abstract:

Ideally soliton can't exist in a fiber when the dispersion distance Z_0 much greater than loss distance. But for proper choice of the initial amplitude and inserting amplifier with proper distance Z_a an optical pulse can propagate in a nonlinear medium like soliton over a distance much greater than the dispersion distance if the pulse is amplified periodically at distances $Z < Z_0$.

Key words: GVD, SPM, Group dispersion, bright soliton, dark soliton, anomalous dispersion, normal dispersion, Soliton period, dispersion length, NLSE, Sock effect, delayed Raman response,

Theory:

In ideal sense a soliton can't exist when the dispersion distance Z_0 much larger than the loss distance. But with proper selection of the initial amplitude of the optical pulse and the distance between the amplifier Z_a , a soliton can exist at a distance much larger than the dispersion distance by amplifying the optical pulse periodically at distances much shorter than the dispersion distance [19]. Thus, the normalized Schrodinger equation that governs the propagation of soliton through an optical fiber having amplifiers with gain G(z) and loss with loss rate Γ in each dispersion distance Z_0[3].

$$i\frac{\partial u}{\partial Z} + \frac{1}{2}\frac{\partial 2_u}{\partial T^2} + |u|^2 u = i[G(z) - \Gamma]u \qquad (1)$$

Where Z, T and Γ be respectively the normalized distance and normalized time and normalized fiber loss.

When average gain of the amplifiers $\langle G(z)\rangle$ is exactly balanced by the fiber loss Γ then the fiber responses completely linear and noise of the amplifier can be neglected and the solution of the equation (1) can be expressed as [3,5]

$$u = \eta sec\eta(T + kZ - \theta_0)\, exp[-ikT + \frac{i}{2}(\eta^2 - k^2)Z - i\sigma_0] \qquad (2)$$

Where η, k are respectively represent the amplitude and speed of the solitary wave.

The relation between the soliton peak power and soliton width (FWHM) $\tau_s\ (psec)$

$$P_o = \frac{(2.9)^2\lambda^3|D|S}{\tau_s^2} \qquad (3)$$

Where S is the effective cross-section of the fiber. Thus the soliton peak power is proportional to the $|D|$ and S respectively.

The group velocity dispersion k'' deforms the linear wave packet and the dispersion length Z_0 in the scale size of t_0 is given by

$$Z_0 = -\frac{t_0^2}{k''}$$

However if we use a soliton of pulse width τ_s and wavelength in an optical fiber of loss rate γ, the Γ is given by[4].

$$\Gamma = \frac{\gamma \tau_s^2}{(1.76)^2(-k''^2)} = \gamma Z_0 \qquad (4)$$

Where

$$Z_0 = \frac{\tau_s^2}{(1.76)^2(-k''^2)} \qquad (5)$$

$$k'' = -\frac{\lambda^2 D}{2\pi C} \qquad (6)$$

Equation (5) represents the expression of dispersion distance.

Thus, from the equation (6) we can conclude that soliton can only exist when $\Gamma \leq 1$ and in order to explain this condition let us consider an example of an optical pulse of pulse width $50\ psec$ in a dispersion shifted fiber of $S = 60\ \mu m^2$ with group dispersion D =1psec/nm/km. In this case the dispersion distance Z_0 is obtained from equation (5) is 625 km and soliton power P_o is obtained from equation (3) is given by $0.626\ mw$ for $\lambda = 1.55\ \mu m$.

In presence of EDFA along the fiber the propagation of soliton is govern by the equation [1]

$$i\frac{\partial u}{\partial Z} + \frac{1}{2}\frac{\partial 2_u}{\partial \tau^2} + |u|^2 u = i\gamma_0(Z)u \qquad (7)$$

The distance Z is normalized to the dispersion distance

$$Z_0(m) \approx 6.07 \times 10^2 \frac{t_s^2(ps^2)}{\lambda^2(\mu m) D(\frac{ps}{nm.Km})} \qquad (8)$$

and the time T is normalized to the characteristic time

$$T_0 = \frac{t_s}{1.76} \qquad (9)$$

Where t_s, D , λ and $\gamma_0(Z)$ are respectively the soliton pulse width, dispersion parameter, carrier wavelength of the pulse and loss-gain function.

$$\gamma_0(Z) = -i\Gamma + [\exp(Z_a\Gamma) - 1] \times \sum_{n=0}^{N} \delta(Z - Z_n)u \qquad (10)$$

Where N is the total number of amplifiers and they are placed uniformly with amplifier spacing Z_a, therefore $Z_n = nZ_a$ and the equation (4) becomes

$$\gamma_0(Z) = -i\Gamma + [\exp(Z_a\Gamma) - 1] \times \sum_{n=0}^{N} \delta(Z - nZ_a)u \quad (11)$$

Because of the rapid variation of the energy of the soliton due to the periodic amplification of the soliton, we make a transformation [2,4,5].

$$u(Z,T) = a(Z)q(Z,T) \quad (12)$$

Where $a(Z), q(Z,T)$ are respectively the rapidly varying and slowly varying functions of Z.

Using equation (6) in (1), we obtain

$$i\frac{\partial q}{\partial Z} + \frac{1}{2}\frac{\partial^2 q}{\partial \tau^2} + a(Z)^2|q|^2 q = 0 \quad (13)$$

Where a satisfy the equation [1]

$$\frac{da}{dz} = \gamma_0(Z)a(Z) \quad (14)$$

By solving the equation (16), we obtain [3]

$$a(Z) = a_0\exp[-\Gamma(Z - nZ_a)] \quad (15)$$

Where $a(Z)$ is a periodic function between $nZ_a < Z < (n+1)Z_a$ and [3]

$$a_0 = \sqrt{\frac{\Gamma Z_a}{(1-\exp(-2\Gamma Z_a)}} \quad (16)$$

Where a_0 be the amplitude of q at Z_0.

Physically the variation of the energy of the soliton is varied according to the equation (16).

The $a(Z)^2$ can be considered as the rapid varying function of Z in the dispersion distance scale [4].

Thus $a(Z)^2$ can be expressed as $a(Z)^2 = A_0 + \tilde{A}(Z)$, with $\langle\tilde{A}(Z)\rangle = 0$ (17)

Where A_0 be the average over one amplifier distance and $\tilde{A}(Z)$ be variation within the amplifier distance.

Similarly we can write $q = q_0 + \tilde{q}(Z)$ with $\langle\tilde{A}(Z)\rangle = 0$ (18)

Where q_0 be the slowly varying function and $\tilde{q}(Z)$ be the rapid varying function and $\langle\tilde{A}(Z)\rangle$ be the average over the amplification period [4].

If we substitute equation (6) and (7) in equation (4) and solving the rapidly varying part of the resultant equation by means of perturbation method, we find

$$\tilde{q} = i\tilde{A}(Z)|q_0|^2 q_0 + O(Z_a^2) \quad (19)$$

From equations (4), (7) and (9) the solution of equation (1) between the two amplifiers can be expressed as.

$$q(Z,T) = a_0 \exp\left(-\Gamma\tilde{Z}\right)(q_0 + \tilde{q}) \quad \text{for } 0 < Z < Z_a \qquad (20)$$

Periodic amplification is required to compensate for fiber loss in optical transmission system. It has been suggested that pre-emphasis of the peak power of the soliton pulse can improve the transmission capacity [12,13].

Conclusion:

Unnecessarily high input power produces more non-soliton parts, therefore we must careful not to use extremely high input power at the pre emphasized input. Thus, there is an optimum condition for maximizing transmission capacity. The amplifier spacing is determined so that the pulse width at the output end of the fiber almost the same as the input end. The pulse regains its amplitude, shape and phase after each amplification and the propagation distance is extended. The amplifier spacing is depend on fiber loss, peak power of soliton, group dispersion D(ps/nm/km), pulse width. This system can be constructed with conventional optical fiber and rare earth doped fiber amplifier pumped by laser diodes. With proper choice of the initial amplitude and amplifier distance a soliton can propagate over a distance much larger than the dispersion distance.

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