International Journal of Electronics Engineering (ISSN: 0973-7383)
Volume 10 • Issue 1 pp. 163-167 Jan 2018-June 2018 www.csjournals.com

Analytical Study and Simulation of TOD in Non linear Dispersive fiber

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Abstract: The increasing transmission rates and link lengths of optical communication systems imply a better acquaintance of the influence of dispersion. As the transmission speed is increased, the influence of higher order dispersion is greater and must be understood. In this work we obtained a solution for a propagating pulse with third order dispersion. We could infer quantitavely the significance of third order dispersion on the pulse shape for high speed transmission systems.

Introduction

In recent years, there has been vast increase of applications in telecommunications sectors that need great amounts of bandwidth services such as interactive multimedia, video conferencing and streaming audio which has made the capacity of the existing optical fiber systems inadequate. Technologies such as Frame Relay and ATM are also requiring increased capacity. The number of Internet users is growing by many folds each year which in turn is also creating additional load and demand on the telephone access networks [11]. With the quick growth of the information industry throughout the world, more consideration is being given to optical fiber communication networks having much higher speed and larger capacity. In optical fiber communication system, dispersion is the major limiting factor as the bit rate and the transmission distance increases. Degradation of the performance of the system occurs due to increased inter-chirp interference and reduced optical power [1-11]. Dynamic dispersion compensation is becoming a concern of vital importance in high-speed optical fiber communication systems operating at 40 Gb/s and beyond as such expansion of the transmission bandwidth results in signal waveform distortion. Even if the transmission bandwidth is limited to a single channel, third-order dispersion (TOD) causes pulses to have trailing ripples which decrease the performance of the ultrahigh speed optical transmission systems [1-11]. Therefore, in such a high bit rate system, it becomes increasingly significant to exactly compensate not only the second-order dispersion, but also the TOD or dispersion slope of the fiber. There have been a number of dispersion-managed (DM) techniques to compensate for the dispersion effects. Among the different dispersion compensation techniques, there are two methods that are very useful, one using the dispersion compensation fiber (DCF) and the other, using optical fiber Bragg Grating (FBG) [11]. However, examination of TOD effect for bit rate of more than 40 Gb/s with actual values of TOD parameters is yet to be addressed. In the present paper, we have examined the impact of TOD on the pulse shape for ultra-high speed system considering group velocity dispersion (GVD) parameter with TOD and evaluated the performance in this ultra-high speed long-haul transmission.

The qualities of optical solitons described so far are based on the NLS equation . when input pulses are so short that $T0<5$ ps, it is essential to include higher-order nonlinear and dispersive effects through Eq.

$$i\frac{\partial u}{\partial \xi} + \frac{1}{2}\frac{\partial^2 u}{\partial \tau^2} + |u|^2 u = \delta_3 \frac{\partial^3 u}{\partial \tau^3} - is\frac{\partial}{\partial \tau}(|u|^2 u) + \tau_R u\frac{\partial |u|^2}{\partial \tau} \quad (1)$$

where the pulse is assumed to propagate in the region of anomalous GVD (β2<0) and fiber losses are neglected (α=0). The parameters δ_3,s, and τ_R administer, respectively, the effects of third-order dispersion (TOD), self-steepening, and intrapulse Raman scattering. Their explicit equations are

$$\delta_3 = \frac{\beta_3}{6|\beta_2|}\frac{1}{T_0} \quad (2)$$

$$s = 1/\omega_0 T_0 \quad (3)$$

$$\tau_R = T_R/T_0 \quad (4)$$

All three parameters changes inversely with pulse width and are insignificant for $T0>1$ ps. They become substantial for femtosecond pulses. As an example, $\delta_3 \approx 0.029$, $s \approx 0.03$, $\tau_R \approx 0.1$ for a 50-fs pulse ($T0 \approx$ 30fs) propagating at 1.55 μm in a standard silica fiber if we take T_R = 3 fs.

Third-Order Dispersion

When optical pulses propagate relatively far from the zero-dispersion wavelength of an optical fiber, the TOD effects on solitons is little and can be considered perturbatively. To study such effects,let us set $s=0$ and $\tau_R= 0$ in Eq. (1) and treat the $\delta 3$ term as a small perturbation.

Using reduced Euler-Lagrange to determine how the soliton parameter evolve with ξ . Now by putting $\epsilon(u)= \delta 3(\partial^3 u/\partial \tau^3)$ in those equation, it is easy to show that amplitude δ, frequency η, and phase ϕ of the soliton are not susceptible to TOD. on the contrary, the peak position q changes as

$$\frac{dq}{d\xi} = -\delta + \delta_3 \eta^2 \quad (5)$$

For a fundamental soliton with η=1 and δ= 0, the soliton peak shifts linearly with ξ as $q(\xi)$. Actually, the TOD slows down the soliton and, consequently, the soliton peak is delayed by an amount that increases linearly with distance. This TOD-induced delay is insignificant in most fibers for picosecond pulses for distances as large as ξ~100 provided that β2 is not nearly zero. What happens if an optical pulse propagates at or near the zero-dispersion wavelength of an optical fiber such that β2 is nearly zero. Considerable work has been done to understand propagation behavior in this regime.

Normalizing the transmission distance to $L_D=T_0^3/\beta_3$ through $\xi'=z/L'_D$, we obtain the following equation:

$$\frac{\partial u}{\partial \xi'} - \mathrm{sgn}(\beta_3)\frac{i}{6}\frac{\partial^3 u}{\partial \tau^3} + |u|^2 u = 0 \qquad (6)$$

where $u = \tilde{N}U$ with $\tilde{N}$ is described by

$$\tilde{N}^2 = \frac{L'_D}{L_{NL}} = \gamma P_0 T_0^3/|\beta_3| \qquad (7)$$

Figure 1 & Figure 2 shows the pulse shape and the spectrum at ξ'=3 for $\tilde{N}=2$ and compares them with those of the input pulse at ξ'=0. The most striking feature is splitting of the spectrum into two well-resolved spectral peaks [9-11]. These peaks denotes the outermost peaks of the SPM-broadened specta.

since the red-shifted crest exists in the anomalous-GVD regime, pulse energy within that spectral band can form a soliton. The energy in the further spectral band dissipates away easily because that part of the pulse experiences normal GVD. It is the trailing part of the pulse that dissipates away with propagation because SPM generates blue-shifted components close to the trailing edge. The pulse shape in Figure 1 display a long trailing edge with oscillations that continues to detach away from the leading part with

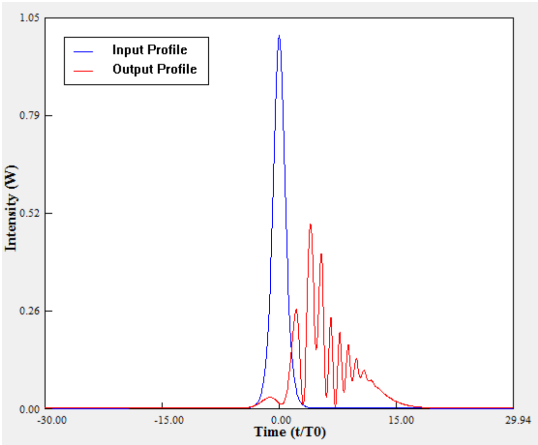

Figure 1 Pulse shape at $z/L'_D=3$ of a hyperbolic secant pulse propagating at the zero-dispersion wavelength with a peak power such that $\tilde{N}$=2. Blue curves show for comparison the initial profiles at the fiber input.

IJEE 0973-7383 International Journal of Electronics Engineering (ISSN: 0973-7383)
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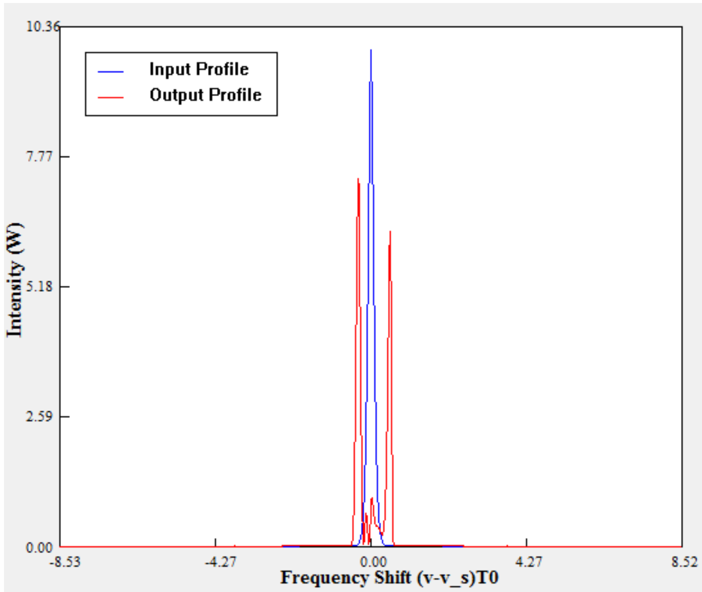

Figure 2 spectrum at $z/L'_D=3$ of a hyperbolic secant pulse propagating at the zero-dispersion wavelength with a peak power such that Ñ=2. Blue curves show for comparison the initial profiles at the fiber input.

increasing ξ'. The significant point to note is that, owing to SPM-induced spectral broadening, the input pulse not at all actually propagate at the zero-dispersion wavelength even if $\beta 2= 0$ initially. in fact, the pulse creates its own| $\beta 2$| through SPM. The effectual value of $\beta 2$ is larger for pulses with higher peak powers. An attractive problem is whether soliton-like solutions exist at the zero dispersion wavelength of an optical fiber. Equation (6) does not appear to be integrable by the inverse scattering method. Numerical solutions show that for Ñ>1, a "sech" pulse evolves over a length $\xi' \sim 10/\tilde{N}^2$ into a soliton that holds about half of the pulse energy. The residual energy is carried by an oscillatory structure near the trailing edge that dissipates away with propagation. This nature of solitons have also been quantified by solving Eq. (6) approximately [4]. generally, solitons at the zero-dispersion wavelength need less power than those occurring in the anomalous-GVD regime. This can be seen by comparing Equations.

$N^2= L_D/L_{NL}=\gamma P_0 T_0^2/|\beta_2|$ and Equation (6). To attain the same values of N and Ñ , the required power is smaller by a factor of $T0|\beta_2/\beta_3|$ for pulses propagating at the zero-dispersion wavelength.

Conclusions

Higher order dispersion is the main factor limiting transmission length in high-speed optical single-mode fiber systems; it reduces significantly the amplitude and broadens the time width of the pulses for systems operating at high speed. From the in-depth analyses, it has been found obvious that the influence of TOD should not be ignored for ultra-high bit rate systems. The outcome of this research will be useful for designing and implementing ultra-high speed long-haul optical fiber communication system

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