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GVD effect and nonlinear pulse propagation in 40Gbit/s optical fiber communication systems

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Abstract

In this paper, group velocity dispersion (GVD) and second-order GVD effects are shortly discussed and then the limitations on the bit rate induced by dispersion or second-order GVD are estimated. For relative higher pulse energy and shorter pulse width in 40Gbit/s systems, self-phase modulation(SPM) is significant. The combined effect of GVD and SPM on the propagation pulses are analyzed through Nonlinear Schrödinger Equation(NLSE).

Keywords: GVD; nonlinear pulse propagation; SPM;

1. Introduction

Several challenges need to be overcome before 40Gbit/s will be widely introduced into optical networks[1]. One of concerns relate to the increase of the bit-rate is GVD[2]. GVD scales with the square of the bit-rate and while not being much of a concern for 2.5Gbit/s, it needs to be accounted for at 10Gbit/s and is a severe problem at 40Gbit/s. For 2.5Gbit/s GVD of the transmission fiber can be left uncompensated for most situations. With 10Gbit/s the tolerance of a receiver is typically in the order of 1000ps/nm and therefore only distances up to 60km of standard single-mode fiber (SMF) with a

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dispersion of 17ps/nm/km are supported without compensation. A widely used method of dispersion management (DM) is to periodically introduce so called dispersion compensating fiber (DCF) for longer, multi-span transmission distances[3,4]. Indeed, in DM propagation of RZ signals dispersion together with nonlinear fiber effects are a major source of signal distortion in optical fiber transmission systems.

In this paper, we will analyze GVD and second-order GVD effects and nonlinear pulse propagation in 40Gbit/s optical fiber communication systems.

2. Group-velocity dispersion effects

GVD is caused by a variation of the group velocity with changes in optical frequency. There is a parameter D (the fiber dispersion parameter in ps/nm/km) describing GVD. For a uniform fiber of length L in m[5]:

$$D = \frac{d}{d\lambda}\left(\frac{1}{v_g}\right) = \frac{d}{d\lambda}\left(\frac{\tau_g}{L}\right) = \frac{1}{L}\frac{d\tau_g}{d\lambda} = -\frac{2\pi c}{\lambda^2}\beta_2 \qquad (1)$$

τ_g is a wavelength-dependent group delay. Over a length range of L, the total delay difference is:

$$\Delta T = D \cdot \Delta\lambda \cdot L \qquad (2)$$

τ_g and D are usually a nonlinear function of wavelength which are shown in figure 1:

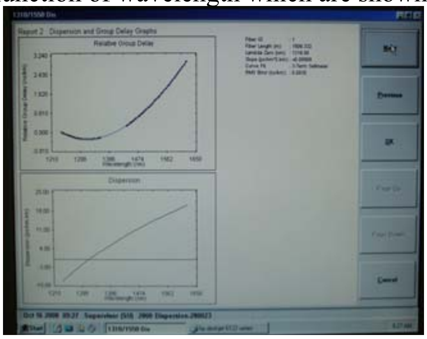

Fig. 1 group delay and group velocity dispersion of standard single-mode fiber

The effect of dispersion on the bit rate B can be estimated by using the criterion $B\Delta T < 1$, by using ΔT from Eq. (2) this condition becomes

$$BL\,|D|\,\Delta\lambda < 1 \qquad (3)$$

The relation between GVD and bit rate-distance can be depicted in figure 2.

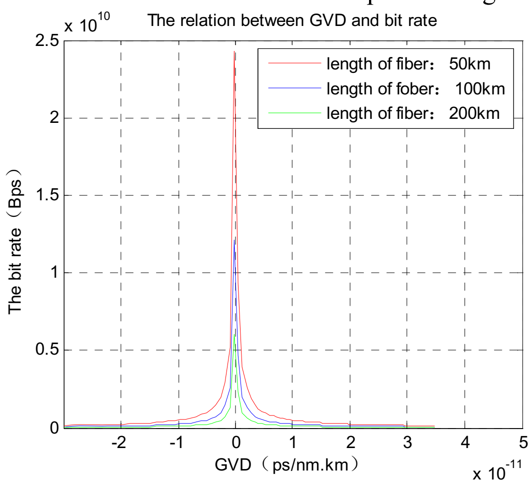

Fig. 2 relation between GVD and bit rate-distance

From above analysis, we get that with 40Gbit/s the tolerance of a receiver is typically in the order of 1000ps/nm and therefore only distances up to 15km of standard single-mode fiber (SMF) with a dispersion of 17ps/nm/km are supported without compensation.

If the first-order GVD is null, then the effect of second-order GVD, known also as third-order dispersion(TOD) must be taken into account. Higher-order dispersive effects are governed by the dispersion slope $S = dD/d\lambda$. The parameter S is also called a differential-dispersion parameter. By using Eq. (1) it can be written as:

$$S = (2\pi c/\lambda^2)^2 \beta_3 + (4\pi c/\lambda^3)\beta_2 \quad (4)$$

When $\lambda \sim \lambda_0$ and $D \sim S\Delta\lambda$. The limiting bit rate–distance product can now be obtained by using Eq.(3) with this value of D. The resulting condition becomes:

$$BL|\beta_3|(\Delta\lambda)^2 < 1 \quad (5)$$

For example, for a Corning SMF-28 with S = 0.090 ps/(km-nm^2) at λ = 1.312μm and a multimode semiconductor laser with $\Delta\lambda$ = 2 nm, the BL product approaches about 6.455 (Tb/s)-km. Further more, TOD will make the original pulse evolves towards a nonsymmetric shape, oscillatory structure following the main temporal component will appear, which is shown in fig3.

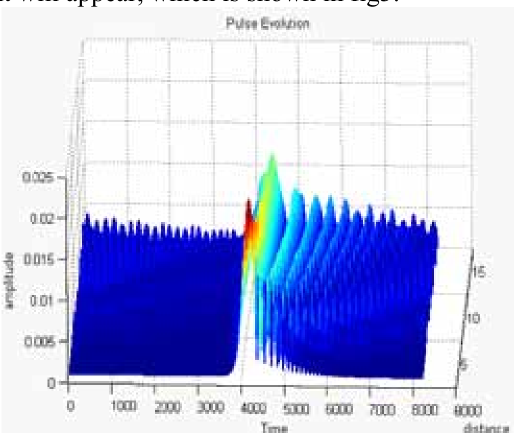

Fig. 3. evolution of pulses affected by β3 (β3>0)

This oscillatory structure will also affects the bit-rate remarkably in 40Gbit/s optical fiber communication systems.

3. Nonlinear pulse propagation

Because the refractive index of the fiber n is intensity-dependent, induces phase shift proportional to the intensity and then creates chirping and pulse degradation. It is significant for 40Gbit/s systems. When the optical field is assumed to maintain its polarization, neglecting fiber loss and TOD, the evolution of slowly varying electric field can be described by a single Nonlinear Schrödinger equation [6].

$$j\frac{\partial U}{\partial z} = \frac{1}{2L_D}\frac{\partial^2 U}{\partial \tau^2} - \frac{1}{L_{NL}}|U|^2 U \quad (6)$$

Where $L_D = T_0^2 / |\beta_2|$, $L_{NL} = 1/\gamma p_0$, $\tau = T/T_0 = (t - z/\upsilon_g)/T_0$, $A(z,\tau) = \sqrt{P_0} e^{-az/2} U(z,\tau)$, T_0 is the time window size and p_0 is the maximum of the electric field intensity. A single chirp-free Gaussian pulse is assumed with 10mw power and 9ps pulse width (which is used in 40Gbit/s systems) as initial signal source. The wavelength, parameter β_2 and γ are 1.550μm, $-20*10^{-27}s^2/m$ and $1.6468W^{-1}km^{-1}$ respectively. The length of the fiber is $1.5L_D$. This simulation is carried out using the MATLAB software through Split Step Fourier method and the result are shown in figure.4.

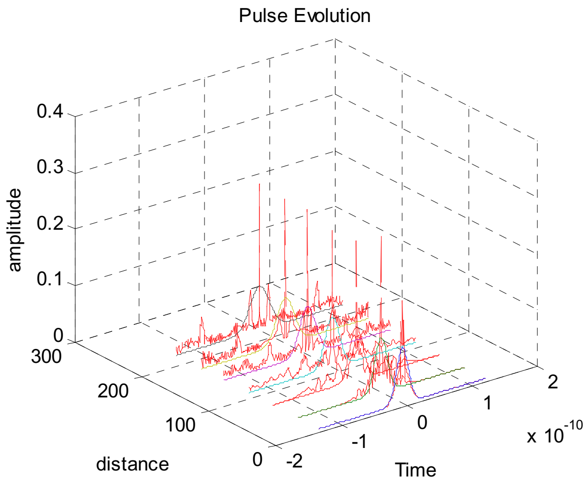

Fig.4. Variation of a free-chirped Gaussian input pulse. Color line: numerical simulations excluding SPM. Red line: numerical Simulations including GVD and SPM

It can be seen that SPM is significant for 40Gbit/s systems, a mass of symmetric oscillatory structure following the main temporal component appear. Indeed, relative higher pulse energy induces phase shift proportional to the intensity and then creates positive chirp, which is linearly chirp in the center of the pulses. The linearly chirp cancel the GVD-induced broadening of the pulse partly, which will finally lead to higher signal-to-noise ratios.

4. Conclusion

GVD and TOD effects are shortly discussed and then the effects of GVD or TOD on the bit rate are estimated. For relative higher pulse energy and shorter pulse width in 40Gbit/s systems, SPM is significant. Relative higher pulse energy induces phase shift proportional to the intensity and then creates positive chirp, which is linearly chirp in the center of the pulses. The linearly chirp cancel the GVD-induced broadening of the pulse partly, which will finally lead to higher signal-to-noise ratios.

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