Optik 123 (2012) 1482–1485

Contents lists available at SciVerse ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

SPM induced limitations for 40 Gbps chirped Gaussian pulses in optical channel

Vinita Tiwari *, Debabrata Sikdar, V.K. Chaubey

Department of Electrical and Electronics Engineering, B.I.T.S. Pilani, Pilani, Rajasthan, India

ARTICLE INFO

Article history:
Received 12 April 2011
Accepted 14 August 2011

Keywords:
Gaussian
SPM
GVD
Pulse width
Chirp
Q-factor

ABSTRACT

An analysis of self-phase modulation (SPM) induced nonlinearities in a 40 Gbps link with chirped Gaussian pulses of different duty cycles has been reported in this paper. In the present analysis only SPM effect has been considered to control the pulse propagation behavior through the fiber by appropriate selection of pulse width, peak power and channel length to suppress the other channel impairments caused by group velocity dispersion (GVD) and third order dispersion (TOD). The effect of SPM on the *Q*-factor for the transmission of 40 Gbps chirped pulses with different initial pulse widths and input peak powers has been investigated. It has been observed that a wider pulse having maximum negative chirp can withstand the nonlinear effect of SPM for relatively higher ranges of input peak power.

1. Introduction

With the increase in the demand of high speed long-haul communication there has been a growing interest in deploying high data rate optical networks over the last decade [1–3]. An Optical fiber in principle can support data rate beyond terabits with an extremely low bit-error rates exploiting the potential of wavelength division multiplexing, time division multiplexing and polarization division multiplexing. High speed time division multiplexed channels require proper pulse shaping inviting detrimental nonlinear effects owing to narrow pulse width [4].

Even though the chromatic dispersion for a fiber at 1310 nm is very low, the advent of EDFA as a line amplifier has shifted the preferred wavelength for optical communication to 1550 nm [5]. In optical communication system NRZ modulation format requires minimum optical bandwidth and minimum optical peak power per bit interval (for a given average power) is mostly preferred [6,7]. However, for higher data rate RZ modulation formats proved themselves better than NRZ in terms of robustness against distortion and time synchronization. Unlike NRZ format, a RZ-modulated signal stream consisting of a sequence of similar pulse shapes is more tolerant to non-optimized dispersion maps. Dependency on the pulse shape to achieve optimum balance between fiber nonlinearities and dispersion makes RZ formats suitable for high data rate links [8,9]. In the present work, RZ format of the modulation has been simulated using an appropriate NRZ modulator and Gaussian optical pulses of different width leading to different duty cycles.

As optical signal attenuates while propagating through the length of the fiber, amplifiers are spaced at certain distances to boost up the signal power to maintain desirable SNR [4,10]. Higher input peak power then would have been a choice to increase the separation distance between amplifiers. But as we increase the input peak power the fiber no longer operates in linear regime rather becomes a nonlinear medium and gives rise to nonlinear effects like SPM [5,11].

For high data rate optical communication link, the reliability of data transmission is degraded by the system impairments like GVD and fiber nonlinearities. The dispersion length L_D and non-linear length L_{NL} provides the length scales over which dispersive or nonlinear effects become important for pulse evolution. Depending on the relative magnitudes of system length L, L_D and L_{NL}, the propagation behavior can be classified in the following four categories [5].

- For $L << L_{NL}$ and $L << L_D$ neither dispersion nor nonlinear effect plays a significant role during pulse propagation.
- For $L << L_{NL}$ and $L \sim L_D$ pulse evolution is governed by GVD and nonlinear effect plays a relatively minor role.
- For $L << L_D$ and $L \sim L_{NL}$ the dispersion effect is negligible compared to the nonlinear effect as long as the pulse has a smooth temporal profile. In this case pulse evolution in the fiber is governed by SPM that produces changes in the pulse spectrum. The nonlinearity-dominant regime is applicable whenever $L_D >> L_{NL}$.
- For L is longer or comparable to both L_D and L_{NL}, dispersion and nonlinearity act together as the pulse propagates along the fiber.

* Corresponding author.
E-mail addresses: vinita@bits-pilani.ac.in (V. Tiwari), dsikdar@bits-pilani.ac.in (D. Sikdar), vkc@bits-pilani.ac.in (V.K. Chaubey).

0030-4026/$ – see front matter © 2011 Elsevier GmbH. All rights reserved.
doi:10.1016/j.ijleo.2011.08.050

SPM gives rise to an intensity-dependent phase shift but the pulse shape remains unaffected. The nonlinear phase shift φ_{NL} increases with fiber length L. The quantity L_{eff} plays the role of an effective length that is smaller than L because of fiber losses [12]. In the absence of fiber losses, i.e. $\alpha = 0$, L_{eff} becomes equal to L. The maximum phase shift φ_{max} that occurs at the pulse center (located at $T = 0$) is given by $\varphi_{max} = L_{eff}/L_{NL} = \gamma P_0 \times L_{eff}$. Thus the physical meaning of the nonlinear length L_{NL} is the effective propagation distance at which $\varphi_{max} = 1$ [4]. L_{NL} is inversely proportional to the input peak power (P_0) of the pulse. So, an increase in P_0 reduces the nonlinear length L_{NL} leading to lower effective propagation distance to achieve the maximum nonlinear phase shift making the channel more phase sensitive for relatively higher input peak power.

Spectral changes induced by SPM are a direct consequence of the time dependence of φ_{NL}. Since the temporally varying phase implies that the instantaneous optical frequency differs across the pulse from its central value ω_0. The time dependence of the difference of instantaneous optical frequency is referred to as frequency chirping. This chirp induced by SPM increase in magnitude with the propagated distance [5]. These SPM generated frequency components broaden the spectrum over its initial width at $z = 0$ for initially unchirped pulses [13].

In this paper, we have analyzed the performance of Gaussian pulse for 40 Gbps optical transmission link with different duty cycles for various input peak power. We considered a dispersion shifted fiber (DSF) followed by a fiber grating to compensate the effects of GVD and TOD so that the effect on the pulse propagation is fully governed by the SPM induced nonlinearity [14].

2. Performance measures

One of the key issues for an effective design of long-haul lightwave communication links is to make the right choice of the performance evaluation criteria. The performance evaluation parameters should provide a platform to carry out comparative investigation and analysis. The most important and widely used measures to evaluate the performance are OSNR, Q-factor, BER, eye closure and jitter [15]. In this work we have carried out the comparative analysis based on Q-factor which can be interpreted in terms of BER and eye closure. Usually for reliable optical communication system operating at a BER of 10^{-9}, the Q-factor comes out to be nearly 6.

3. System simulation and results

Fig. 1 shows the simulation setup of 40 Gbps optical transmission link to study SPM induced nonlinear effects. Simulation has been carried out using commercial package OptSim™. NRZ electrical modulator and optical Gaussian pulse generator have been used as input to MZM to simulate RZ coded optical pulses as shown in the simulation setup. Duty cycle of the RZ optical pulses coming out from MZM can be varied by changing the initial pulse width of the Gaussian pulse generator.

In the simulation we have considered a DSF of 50 km length with attenuation α as 0.2 dB/km having dispersion D as 0.2 ps/km nm and dispersion slope S as 0.07 ps/nm^2/km at 1550 nm, nonlinear refractive index n_2 as 3×10^{-20} m^2/W and core effective area A_{eff} as 60.805 μm^2 [16]. Input peak power (P_0) of the pulse is varied from 10 mW to 80 mW. Amplitude dual-arm Mach–Zehnder modulator with offset voltage of 0.5 V, extinction ratio of 20 dB and 3 dB average power reduction due to modulation. Attenuation of the optical splitter is 0 dB. PIN diode with quantum efficiency of 0.7, responsivity of 0.8751 A/W, dark current of 0.1 nA and 3 dB bandwidth of 20 GHz has been used. The simulation has been carried out for chirped Gaussian pulse with duty cycle of 33.3%, 50% and 66.67%.

In the present work, we have also considered chirping of the light source while studying the effect of SPM induced nonlinearities with the increase in input peak power of the pulse. Simulation has been done for chirp parameter $C = -1.0, -0.5, 0, 0.5$ and 1.0.

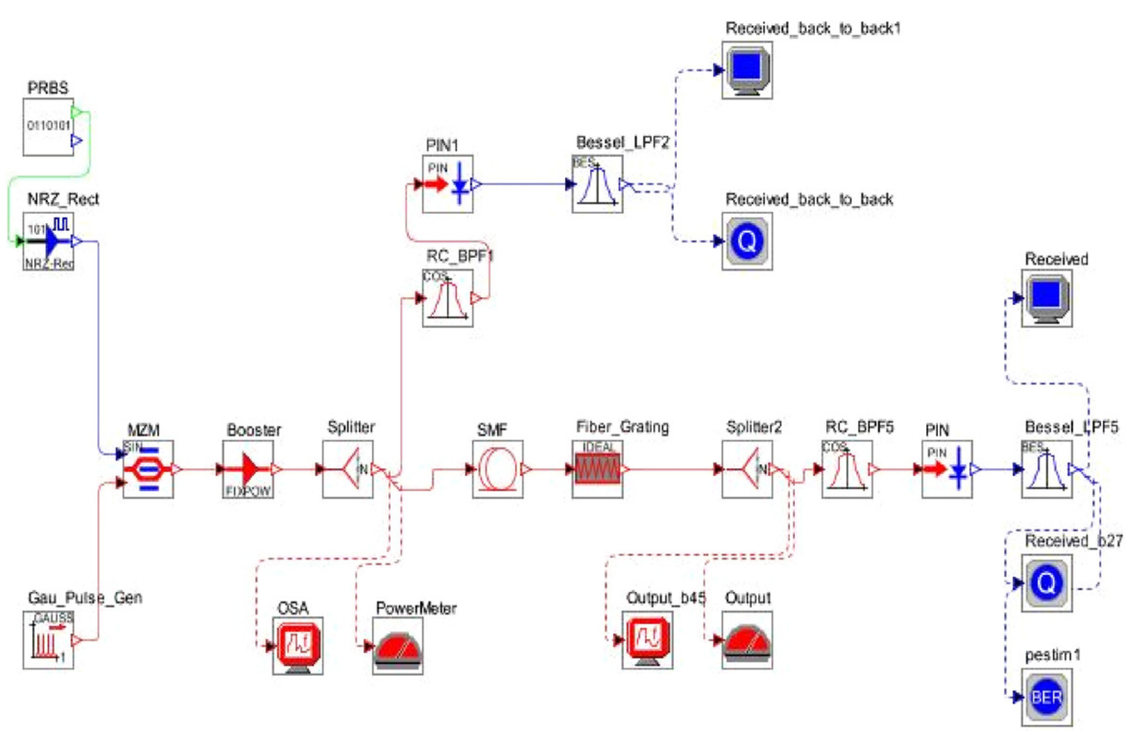

Fig. 1. Layout for 40 Gbps link to study SPM effect.