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10 Gbps optical soliton transmission link using in-line SOA on standard SMF at 1.3 μm

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Abstract

In this paper, 10 Gbps optical soliton transmission link using in-line semiconductor optical amplifiers (SOAs) for already installed standard single mode fibers (SMF) at 1.3 μm wavelength has been reported. The pattern effect and the impact of chirp on pulse propagation after amplification have been investigated. The observations are based on modeling and simulation optical soliton transmission link. Optical soliton pulse transmission over distances of the order of several hundreds of kilometers has been shown with and without initial chirp.

Keywords: Soliton; SOA; SMF; GVD; Kerr nonlinearity

1. Introduction

Recent progress in the development of optical amplifier technology has stimulated investigations on the fifth generation of optical transmission systems design as well as studies of different alternatives to upgrade existing optical networks. Most of the already installed fiber-optic links are operating at the wavelength of 1.3 μm using conventional single mode fibers (SMF). Instead of 1.3 μm wavelength one wants to use 1.55 μm wavelength to reduce the transmission loss. Replacement of electro-optical regenerators by optical amplifiers in already installed fiber-optic networks can further allow a substantial increase in transmission capacity of the optical systems and networks. In the third optical window, around 1.55 μm wavelength, erbium-doped fibers are considered for the upgrading of existing links, even if in this window the standard SMF, which constitute the majority of the installed fibers, show a high-chromatic dispersion or group velocity dispersion (GVD).

A promising way to upgrade installed optic network is to exploit the 1.3 μm optical window, where the step-index fibers have their zero dispersion wavelength, using wide-bandwidth polarization-insensitive semiconductor optical amplifiers (SOAs), that have been mentioned in [1]. The advantages of using SOA as in-line single-channel optical amplifiers are: low dispersion of the SMF at this carrier wavelength and attractive features of SOAs. The two disadvantages of using SOA as in-line single-channel optical amplifiers are: saturation effects, which lead to non-equal amplification of pulses in the pattern in the case of high-bit-rate transmission and

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additional chirp that a pulse acquires after passing an amplifier.

This model of using SMF at 1.3 μm takes advantage of both the low dispersion of the SMF at this carrier wavelength and attractive features of SOAs with soliton pulse propagation. The SOAs cover a broad wavelength range from 0.7 to 1.6 μm, they are pumped electrically and are substantially cheaper than EDFAs. Therefore, the SOA is the natural candidate for incorporation in all-optical transparent transmission systems and networks.

The feasibility of 10 Gb/s transmission over a 500 km optical link consisting of SMF and in-line SOAs was explored in [1–5]. Herein the work has been extended by investigating the pattern effect and the impact of chirp on pulse propagation after amplification. Further, optical soliton pulse transmission over distances of the order of several hundreds of kilometers has been shown with and without initial chirp. In order to evaluate the system performance, we have carried out simulations as a function of operating wavelength and input pulse power.

2. System description and simulation

We have carried out simulations to investigate the pattern effect and chirp that the pulse acquires after amplification at 10 Gb/s transmission over a distance ranging from 360 to 432 km optical link consisting of SMF at 1.3 μm and in-line SOAs with optical soliton source input peak power of 21.7 mW and is biased at −100 dB m. The width of the optical soliton pulse is fixed as 0.2 bit with linear chirp factor equal to zero in case-I and within 0.3–0.6 in case-II.

The simulations have been carried out at fixed bit rate:

$B = 10\,\mathrm{Gb/s}$, $\mathrm{TB} = 100\,\mathrm{ps}$, $\mathrm{TFWHM} = 20\,\mathrm{ps}$, $T_0 = 0.567$ TFWHM $\sim 11.34\,\mathrm{ps}$ and bit pattern …0001011001… which is preceded and followed by three zero's generating sequence length of 16 bits. The dominant fiber parameters considered during simulation are the Kerr non-linearity coefficient

$$\gamma = \frac{n_2 \omega_0}{c A_{\mathrm{eff}}}$$

for the fixed values of non-linear refractive index

$$n_2 = 2.6 \times 10^{-20}\,\mathrm{m}^2/\mathrm{W},$$

$$\omega_0/c = 2\pi/\lambda = 2\pi/1.3 \times 10^{-6}\,\mathrm{m}^{-1},$$

$$A_{\mathrm{eff}} = 62.8\,\mu\mathrm{m}^2$$

The Kerr non-linearity coefficient will be

$$\gamma = 2\left[\frac{1}{\mathrm{km}\,\omega}\right].$$

The linear losses for 45–54 km long SMF are 20 dB. This is unsaturated single pass gain required from SOA. To obtain this gain, the following parameters have been used.

The inner losses are $2000(\mathrm{m}^{-1})$ and the line width enhancement factor = 5. $P_{\mathrm{sat}} \sim 30\,\mathrm{mW}$ and carrier lifetime $t_c = 200\,\mathrm{ps}$. Therefore, $E_{\mathrm{sat}} \sim 6\,\mathrm{pJ}$. Our default values of the SOA component are

$$\Gamma = 0.25 \to E_{\mathrm{sat}} - 5.2\,\mathrm{pJ}.$$

We have considered eight spans with SOAs and the fiber length ranging from 45 to 54 km and losses of 0.4 dB/km. Soliton propagation shows a good stability, in terms of tolerance of the input power, for $\beta > -1.5\,\mathrm{ps}^2\,\mathrm{km}$

$$\beta_2 = \frac{-\lambda^2 D}{2\pi c} \approx -1.5(\mathrm{ps}^2/\mathrm{km}),$$

$$D = 1.67(\mathrm{ps/nm\,km}),$$

$$L_{\mathrm{D}} = T_0^2/|\beta_2| \approx 85\,\mathrm{km}.$$

While simulating the effects of group delay and third-order dispersion are not taken into account. After each fiber, the signal is amplified with SOA. Therefore, $L_{\mathrm{A}} = 45$–$54\,\mathrm{km}$. Hence the condition $L_{\mathrm{A}} < L_{\mathrm{D}}$ is satisfied.

Optical amplifiers are placed periodically along the fiber link such that fiber losses between two amplifiers are exactly compensated by the amplifier gain. An important design parameter is the spacing L_{A} between amplifiers—it should be as large as possible to minimize the overall cost. For nonsoliton systems, L_{A} is typically 80–100 km. For soliton systems, L_{A} is restricted to much smaller values because of the soliton nature of signal propagation [6].

The physical reason behind smaller values of L_{A} is that optical amplifiers boost soliton energy to the input level over a length of few meters without allowing for gradual recovery of the fundamental soliton. The amplified soliton adjusts its width dynamically in the fiber section following the amplifier. However it also sheds a part of its energy as dispersive waves during this adjustment phase. The dispersive part can accumulate to significant levels over a large number of amplification stages and must be avoided [7].

3. Results and discussion

Based on simulation the results have been reported on the pattern effect with and without chirp for the soliton pulse propagation at 10 Gb/s transmission over a distance ranging from 360 to 432 km at 1.3 μm and in-line SOAs with optical input peak power of 21.7 mW. The results have been mentioned for Case-I (without initial chirp at different span lengths) and Case-II (with varied initial chirp factor at fixed span length).

3.1. Case-I (without initial chirp at different span lengths)

Fig. 1(a) shows the initial pattern for the input signal while Fig. 1(b)–(f) show the pattern of pulses after 360, 376, 400, 416 and 432 km transmission in SMF optical network with periodic amplification with SOA using optical soliton source at different span length of 45, 47, 50, 52 and 54 km, respectively.

In this figure from (b) to (f), we have observed the pattern effect that leads to a reduction in the gain of the pulses after the first one in the first group. The optimum results are obtained for 400 and 416 km long optical communication link as observed in Fig. 1(d) and (e). Further as shown in Fig. 1(f), soliton breaks up in a stream of pulses due to the presence of soliton instability effect induced by the periodical amplification, and the system performance becomes very poor.

Regarding our default parameters, the carrier lifetime is approximately 1.4 ns even for the last pulse, which is at a distance of approximately 1 nm from the first one. It follows from the fact in case of soliton signals, the time duration of the pulse is much shorter than the carrier life time, so there is not enough time for the gain to recover

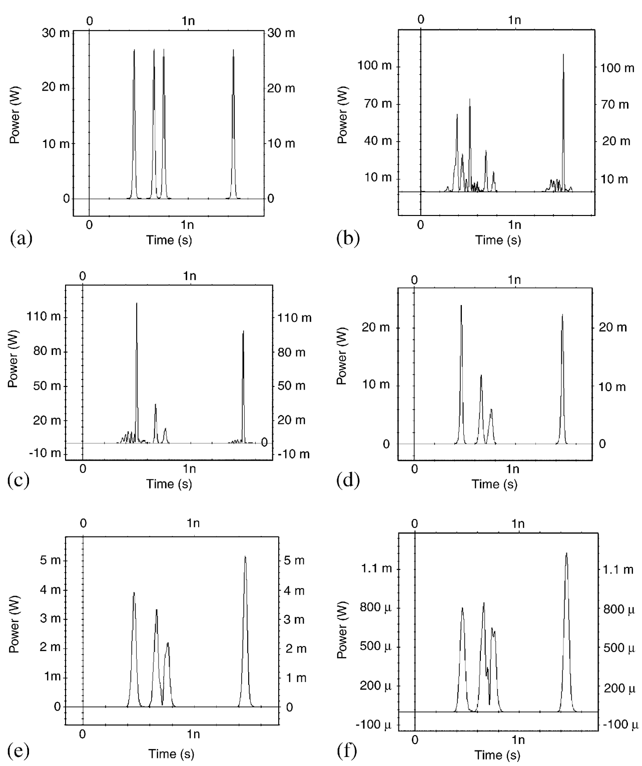

Fig. 1. Soliton signal at: (a) input and soliton output signal at $\beta_2 = -1.5\,\text{ps}^2/\text{km}$ and different span lengths signal at (b) 360 km, (c) 376 km, (d) 400 km, (e) 416 km and (f) 432 km.

completely. It is also pointed out that the presence of the gain saturation limits the level of the power.

Optical soliton source which generates Sec hyperbolic Pulse can contribute linear chirp but in our system under consideration, we have taken the chirp factor to be equal to Zero for case-I. But however due to inherent properties of Soliton source and SOA, the chirping effect is observed which is bound to occur. Fig. 2(a) shows the input chirp while Fig. 2(b) shows the output chirp. It has been further observed that the output chirp remains constant throughout after amplification when measured at 360, 376, 400, 416 and 432 km.

Fig. 3 shows the three-dimensional view of the optical power spectrum with respect to fiber length and time for the output signal measured at 400 km.

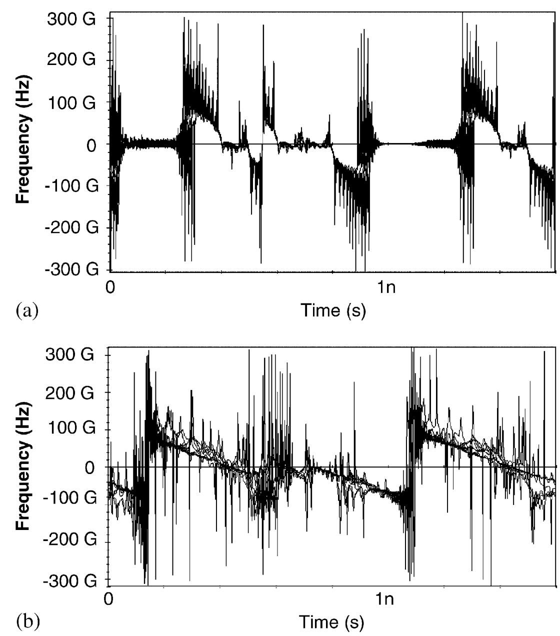

Fig. 2. Signal chirp for case-I: (a) before amplification and (b) after amplification.

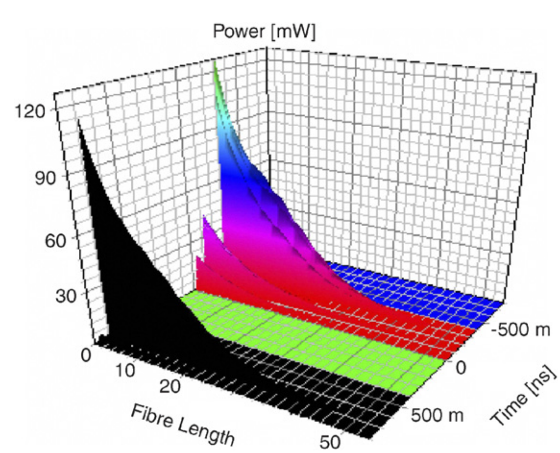

Fig. 3. 3-D view of the optical power spectrum.

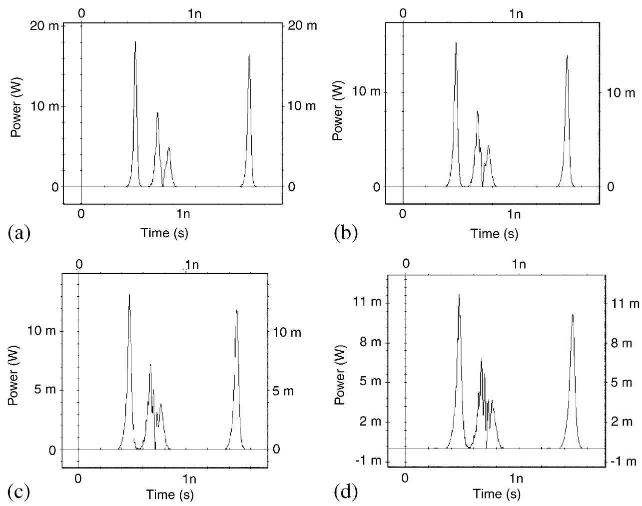

Fig. 4. Signal at: (a) input chirp 0.3; (b) input chirp 0.4; (c) input chirp 0.5 and (d) input chirp 0.6.

3.2. Case-II (with varied initial chirp factor at fixed span length)

In Fig. 4, the pattern effect has been studied under the influence of initial chirp factor ranging from 0.3 to 0.6 at fixed span length. It has been observed that there is no change in shape of the soliton pulses upto a chirp factor equal to 0.4 as shown in Fig. 4(a) and (b) whereas the shape of the pulses starts deteriorating for chirp factor more than 0.4 as observed from Fig. 4(c) and (d) and the pulses start merging into each other beyond a chirp factor ~0.6. Taking into account the above observations it is recommended that the optical source with initial chirp greater than 0.4 is not preferable using in-line SOAs in an optical soliton transmission link.

4. Conclusion

Here an investigation on optical soliton transmission link with in-line SOA at 1.3 μm has been carried out to show in which conditions for the best performance can be achieved with and without initial chirp at different span lengths. Results show that soliton pulses when propagated with a $\beta_2 = -0.5\,\mathrm{ps}^2/\mathrm{km}$, indicate the pattern effect for soliton propagation best suited for transmission upto the distance of 400 km with the use of inline SOA over existing 1.3 μm fiber-optic transmission links. It is further concluded that the chirp factor upto 0.4 for optical soliton source is permissible for soliton pulse propagation with in-line SOAs for the distance upto 400 km.

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