ERROR FREE 80 Gb/s SOLITON TRANSMISSION OVER TRANS-OCEANIC (>8,000 km) DISTANCES USING FAST SATURABLE ABSORBERS AND DISPERSION DECREASING FIBRE

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Introduction

We present a numerical study of the use of fast saturable absorbers in conjunction with dispersion decreasing fibre (DDF) to achieve enhanced transmission of 80 Gb/s solitons over ultralong distances (8,350 km) with an amplifier spacing of 50 km. Optical solitons are an attractive solution to the problems imposed by dispersion and self-phase modulation in high bit rate, long distance, optical fibre telecommunication systems. Optical time division multiplexing (OTDM) of narrow soliton pulses allows these systems to be uprated to ultrahigh bit rates without any need for ultrahigh speed electronic circuits. However, the resultant close pulse spacing and short pulse widths present significant challenges in implementing such systems over ultralong distances. In particular, physical fibre properties such as higher-order dispersion and the Raman effect, which do not play a significant role in the dynamics of solitons at low bit rates, become of increasing concern at ultrahigh bit rates.

In uniform dispersion fibre, stable propagation of such solitons is ultimately limited by the build-up of dispersive waves over multiple amplification stages interacting with the pulse stream and eventually destroying it [1]. For 80 Gb/s soliton systems operating over dispersion shifted fibre, maximum transmission distances of 80 km using polarisation division multiplexing [2] and 500 km using unequal amplitude solitons [3] have been achieved experimentally.

To achieve stable propagation of 80 Gb/s solitons over ultralong distances with realistic amplifier spacings it is clear that we need to look beyond the experimental systems already reported in the literature. One possible way to increase both the amplifier spacing and the overall transmission distance is to compensate for the decrease in self-phase modulation due to fibre loss by exponentially decreasing the dispersion of the fibre at the same rate as the energy loss. In such DDF, analysis has shown that further soliton control is needed to reduce the jitter of short pulsewidth solitons to a tolerable level over ultralong distances [4,5].

Approaches which have been presented include phase conjugation [6,7] and sliding narrow band optical filters [8]. At low bit rates, fast saturable absorbers have been shown to enhance soliton propagation in uniform dispersion fibre [9]. In this paper we examine the feasibility of using fast saturable absorbers in conjunction with DDF and narrow band optical filters to enhance soliton propagation at bit rates of 80 Gb/s.

System model

A schematic of the modelled system is shown in Figure 1. Within the system each amplifier was spaced by a 50 km span of DDF. Saturated amplifiers were assumed which maintain the average energy of the pulse stream constant and an inversion factor $N_{in} = 1$ was used for amplified spontaneous emission (ASE). Each amplifier was followed by a fast saturable absorber with absorbance $a_d(P) = (1+P/P_s)^{-1}$ where the saturation power $P_s = 5$ mW, and an optical filter with amplitude transmission function $H(f) = (1+2|f|/B)^{-1}$, where $f$ is the frequency relative to the centre frequency and we choose $B = 260$ GHz to help reduce soliton self-

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frequency shift due to the Raman effect. Propagation in the fibre was modelled using the split-step Fourier method with the following parameters: loss $\alpha = 0.21$ dB/km, first-order dispersion $D(z) = D(0) \exp(-\alpha z)$, where $D(0) = 0.18$ ps/(nm km), higher-order dispersion $dD/d\lambda = 0.061$ ps/(nm$^2$ km), Raman coefficient $T_R = 6.0$ fs, nonlinear index coefficient $n_2 = 2.7 \times 10^{-20}$ m$^2$ W$^{-1}$, effective core area $A_{eff} = 50$ $\mu$m$^2$, and an operating wavelength of 1550 nm. A linear time shift was applied to the pulse stream to keep it within the simulation window. The soliton pulses were launched with peak powers of 92 mW, and FWHMs of 2.3 ps.

Results and discussion

The effect of the saturable absorbers can be seen in Figure 2 where a pulse is shown after propagation over three fibre spans (150 km) without any soliton control (a) and with a saturable absorber inserted after every amplifier (b). The saturable absorber preferentially suppresses the non soliton dispersive wave seen in Figure 2 (a). Over multiple fibre spans the saturable absorber can significantly enhance the propagation of solitons and reduce interaction between neighbouring solitons [9].

Figure 3 (a) shows stable soliton propagation over a distance of 10,000 km for the system shown in Figure 1. Figure 3 (b) shows the propagation of two solitons initially in phase with a time separation of 12.5 ps (corresponding to a bit rate of 80 Gb/s) and showing very little soliton-soliton interaction over a distance of 10,000 km.

For Q factor calculations a 64 bit pseudorandom soliton bit pattern was passed through the system which included a 40 GHz bandwidth, second-order Butterworth, post detection filter. Over a distance of 10,000 km the average gain of each amplifier was 12 dB with a standard deviation of 0.1 dB and a mean power output power of 6.9 dBm. The Q factor evolution over a distance of 8,000 km can be seen in Figure 4 along with the eye diagrams at 50 km and 8,350 km. The Q factor falls below a value of 6 (corresponding to a bit error rate of $10^{-9}$) for distances greater than 8,350 km. This distance moves to 9,150 km if ASE noise is not included in the model, 8,200 km if higher-order dispersion is ignored and greater than 10,000 km (Q = 9.9 at 10,000 km) if the Raman effect is omitted. From these figures and examination of the eye diagrams we expect the dominant limit to be that of timing jitter caused by the Raman effect. Also shown for comparison in Figure 4 is the Q factor versus transmission distance when the saturable absorbers are removed from the system. Without the saturable absorbers the error free transmission distance drops to 1,200 km.

Conclusion

In conclusion, our numerical simulations for an 80 Gb/s soliton communication system show that with the use of DDF and fast saturable absorbers ultralong transmission distances can be realised with an amplifier spacing of 50 km. Possible candidates for fast saturable absorbers include ion implanted [10], electrically biased [11] or low temperature MBE grown [12] multiple quantum wells or nonlinear optical loop mirrors [13].

References


Figure 1. Schematic of 80 Gb/s soliton transmission system (SA = saturable absorber).

Figure 2 (a) Pulse after propagation over three fibre spans without any soliton control. (b) Pulse after propagation over three fibre spans with saturable absorbers inserted after every amplifier.
Figure 3. (a) Pulse after every fourth amplifier. (b) Contour plot showing little interaction between two 80 Gb/s solitons over a distance of 10,000 km.

Figure 4. Q factor against transmission distance and eye diagrams after 50 km and 8,350 km. Also shown dashed is the Q factor versus transmission distance when the saturable absorbers are removed from the system.