Investigation of 80 Gbit/s signal transmission with carrier-suppressed return-to-zero signal format

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Abstract: Carrier-suppressed return-to-zero (CS-RZ) signals combine the advantages of stable propagation exhibited by RZ signals with reduced optical spectral width, allowing long haul WDM transmission with high spectral efficiency. Simulations were carried out comparing the transmission performance of 80 Gbit/s conventional RZ and CS-RZ formats for a range of fibre dispersion values.

1. Introduction

In optical fibre networks, one needs to cope with physical effects that distort the signal, such as power attenuation, dispersion and non-linear effects. As a consequence, amplifiers are used to keep the power of the signal the same along the fibres, and likewise dispersion can be cancelled by a physical modification of the fibre, consequently the shape of the signal remains the same (if non-linear effects are not taken in consideration). As amplification and reshaping need to be regularly used to avoid huge modification of the signal, optical networks can be designed as a succession of spans. Each span can be considered as a fibre ended with an amplification system and a reshaping system. Hence the physical effects that modifies the signal are regularly cancelled. Such a system is represented in Fig. 1.

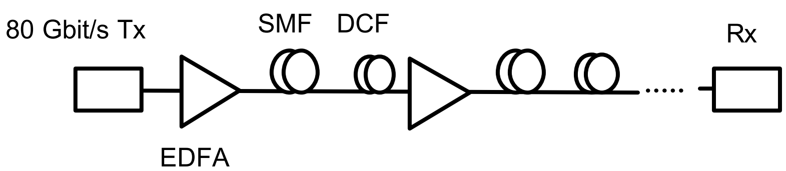

Figure 1: Transmission system configuration, employing of single mode fibre (SMF), in-line dispersion compens ating fibre (DCF) and erbium-doped fibre amplifiers (EDFA).

Nonlinear effects in the fibres depend on the power of the signal. Self phase modulation (SPM), the main non-linear effect in single channel propagation induces a phase shift in the signal. That phase shift is given by: $\phi = \gamma P L$, where γ is the fibre non-linear coefficient, given by, $\gamma = n_2\omega_0 / cA_{eff}$ (n_2 is the non-linear index coefficient, A_{eff}, the effective area of the fibre), L is the length of fibre, P is the optical power. Nonlinear effects induce pulse broadening and interaction between adjacent pulses, resulting in an increase the eye-closure of the received signal.

Increased WDM channel data-rates and narrower channel spacing are essential to achieve the spectral efficiency and capacities required in future optical networks. In addition, increased optical amplifier spacing and distances between 3R regenerators lead to the requirement of new signal formats which allow stable propagation over long distances with high launch powers. The use of return-to-zero formats and soliton pulses has been shown to achieve long distance transmission [1], but the short pulses have a wider optical spectrum compared to the NRZ format, reducing the spectral efficiency that can be achieved.

Recently, a new format has been investigated, termed carrier-suppressed return-to-zero (CS-RZ), in which pulses in adjacent bit slots are transmitted with an optical π phase difference (Fig. 2). This has the effect of removing the optical carrier component in the optical spectrum, and reducing the spectral width by half, allowing closer WDM channel spacing and hence increasing the possible spectral efficiency to >0.4 bit/s/Hz [2]. In this paper, we describe split-step Fourier simulations investigating the robustness of 80 Gbit/s CS-RZ pulses to the fibre nonlinear effects of self-phase modulation (SPM) and adjacent pulse interaction, in comparison to conventional RZ signals.

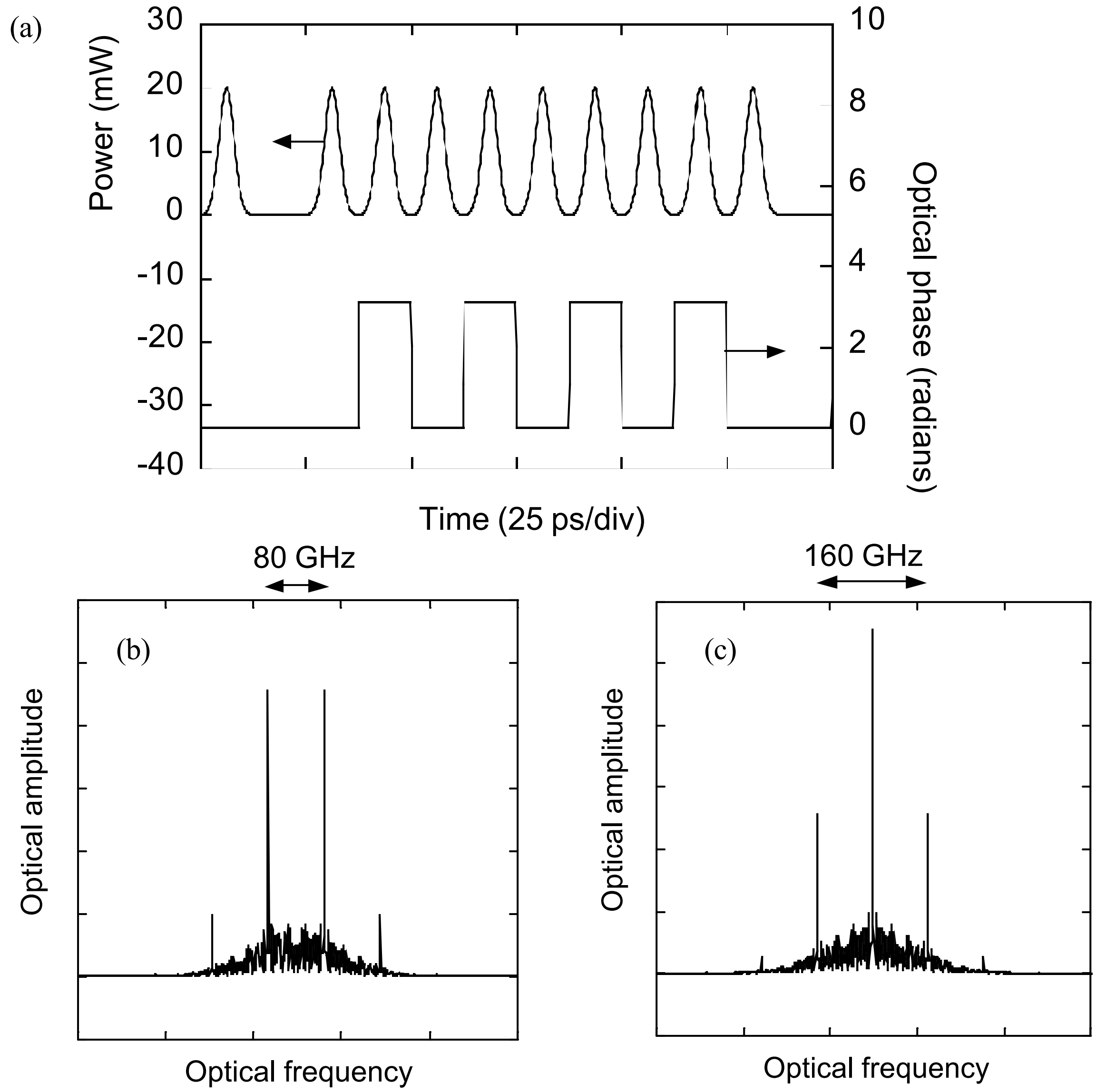

Figure 2: (a) Intensity and phase waveforms of carrier-suppressed RZ signal. (b) Optical spectrum of an 80 Gbit/s CS-RZ signal. (c) Optical spectrum of an 80 Gbit/s conventional RZ signal.

2. Simulations

The multi-span transmission system considered (Fig. 1) comprised 60 km spans of single mode transmission fibre with the dispersion of each span compensated by dispersion compensating fibre (DCF). The dispersion map was optimized for a range of optical launch powers and values of fibre dispersion, including standard single-mode fibre (SSMF, D = 17 ps/nm/km) and non-zero dispersion shifted fibres (NZ-DSF, D = 1.6, 3.1, 6.3 and 12.5 ps/nm/km). Pulses with T_{FWHM} = 5 ps and peak power of 20 mW were used. The propagation of a 128 bit random sequences was simulated using the split-step Fourier algorithm.

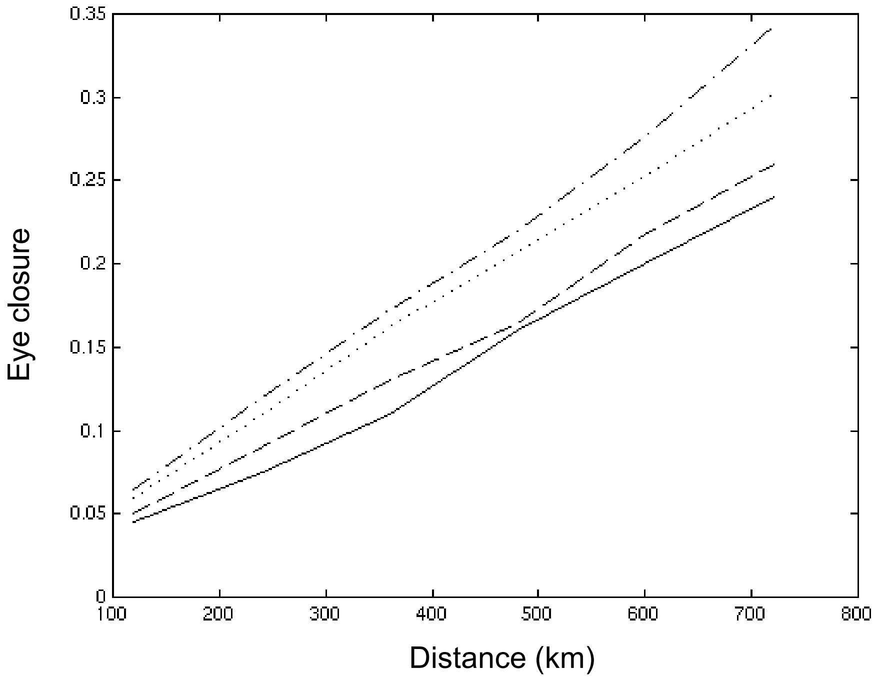

Figure 3: Eye closure vs transmission distance for an 80 Gbit/s conventional RZ signal with 20 mW pulse peak power, 5 ps pulses and 60 km EDFA span length with in-line dispersion compensation.

Fig. 3 shows the eye opening penalty for conventional RZ pulses for transmission distances up to 720 km (12 spans). Increasing the value of dispersion of the transmission fibre led to an increase in the eye opening penalty. This is a result of the increased pulse broadening during propagation. Although the dispersion is fully compensated, i.e. the DCF recompresses the pulses at the end of each span, the overlapping adjacent pulses during transmission leads to non-linear pulse interaction. With non-zero dispersion shifted with D = 1.6 ps/nm/km, the eye closure was 24% after transmission over 12 spans. With standard fibre this value increased to 34% due to the increased non-linear distortion.

Next, the same calculations were performed, but with the carrier-suppressed RZ signal format. The same system parameters were used, and the resulting eye opening penalties are plotted in Fig. 4. As with the conventional RZ signals, increasing the fibre dispersion resulted in increased non-linear distortion. The distortion was very similar to that observed with conventional RZ, with eye closure of 22% for D = 1.6 ps/nm/km and 33% for D = 17 ps/nm/km after transmission over 720 km. This result demonstrates that the CS-RZ format can be used without significantly reducing the error-free transmission distance due to self-phase modulation and pulse interactions.

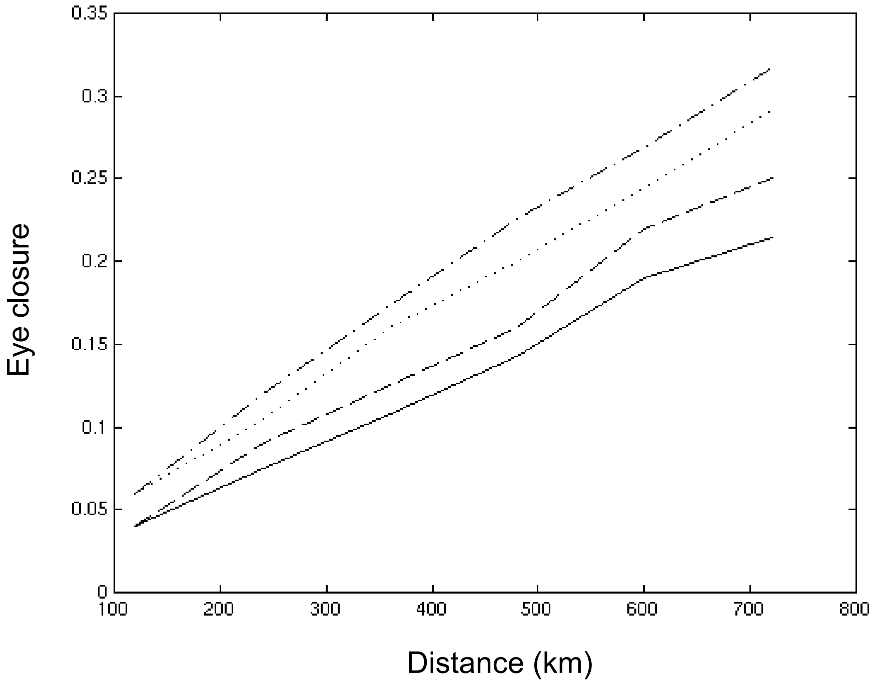

Figure 4: Eye closure vs transmission distance for an 80 Gbit/s carrier-suppressed RZ signal with 20 mW pulse peak power, 5 ps pulses and 60 km EDFA span length with in-line dispersion compensation.

3. Summary

The carrier-suppressed return-to-zero pulse format is attractive due to its narrow spectral width. In this paper, simulations confirmed that it allows stable long distance transmission similar to conventional RZ pulses. An 80 Gbit/s channel was simulated encoded using 5 ps pulses with 20 mW peak power. The eye opening penalty was comparable with both types of signal, and the highest error-free single channel transmission distance was achieved in using non-zero dispersion shifted fibre with low dispersion values. Future work will assess the performance for the multi-WDM channel case.

References

[1] N. J. Smith, N. J. Doran, W. Forysiak, F. M. Knox "Soliton transmission using periodic dispersion compensation" J. Lightwave Tech. 15, 10, pp. 1808-1822, 1997.

[2] Y. Zhu, W. S. Lee, C. Scahill, D. Watley, C. Fludger, P. Bontemps, M. Jones, G. Pettitt, B. Shaw, A. Hadjifotiou, "16-channel 40 Gb/s carrier-suppressed RZ ETDM/DWDM transmission over 720 km NDSF without polarization channel interleaving", Proc. Conference on Optical Fiber Communications, OFC2001, paper Thf4-2, Anaheim, March 2001.