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Performance improvement by positioning DCF non-symmetrically in a periodic amplified re-circulating loop for long-haul optical soliton transmission link

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Abstract

In this paper, we have carried out simulative performance analysis by positioning the DCF non-symmetrically in a periodic amplified re-circulating loop for optical soliton transmission link over a long haul. The investigations indicate that relatively stable pulses can propagate in a mid-compensated optical soliton transmission over a long-haul dispersion-managed soliton regime in a fiber link with loss and periodic amplification by keeping the average dispersion small but non-zero. Here non-zero anomalous fiber dispersion equal to 6 ps/nm is maintained by inserting DCF in the beginning, middle and end of the fiber loop. Here it is demonstrated that solitons can propagate even when β_2 varies along the fiber length up to transmission distance of 18,000 km.

Keywords: Soliton; GVD; DCF; Dispersion-compensated

1. Introduction

Recently, a variety of methods for sending optical solitons over long distances have been developed with the use of erbium-doped fiber amplifiers [1–6]. For example, synchronous modulation with optical filters allows for unlimited-distance soliton transmission because evolution of noise is suppressed [4]. The sliding frequency filter technique can also reduce the noise, and stable soliton transmission has been achieved for over 10,000 km [5]. As long as the average group velocity dispersion (GVD) is anomalous, a soliton can propagate even in fibers with normal GVD [6]. Dispersion allocation can be used to construct transmission lines with a suitable average GVD from many fibers that have different GVD's. This technique made it possible to undertake a soliton communication field trial very easily using the conventional fiber cable already installed for commercial systems, and 10–20 Gb/s soliton signals have been successfully transmitted over 2000 km in the Tokyo metropolitan optical network [7]. Suzuki et al. recently reported an allocation technique in a "soliton" system, where the average dispersion is zero. They succeeded in stable pulse transmission over 10,000 km at 20 Gb/s [8]. However, it is not clear as to what kind of nonlinear pulse is propagating because, in principle, no solitons can exist for zero-average GVD. Further, the transmission improvement in ultra-long dispersion-managed soliton WDM systems by using pulses with different widths has been reported in [9]. The proposed

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method was suitable for transmission distances beyond 3000 km; however, there is stipulation of input pulses with different widths.

Dispersion management in the single-mode fiber links can be accomplished in many ways [10], though the most widely used approach employs lengths of transport fiber of opposite dispersion characteristics to the principal fiber in the link, usually standard single-mode fibers fiber.

Depending upon the positioning of dispersion-compensating fiber (DCF) non-symmetrically in a periodic amplified re-circulating loop for optical soliton transmission link over a long haul, the dispersion compensation has been categorized into the three implementations: pre-compensation, post-compensation and mid-compensation. In the pre-compensation scheme, the DCF is placed prior to the SMF. In the post-compensation scheme, the DCF is placed after the SMF and in the mid-compensation scheme, the DCF is placed in between the consecutive SMF and EDFAs.

In this paper, we have investigated that relatively stable pulses can propagate in mid-compensated optical soliton transmission over a long-haul dispersion-managed soliton regime in a fiber link with loss and periodic amplification by keeping the average dispersion small but non-zero.

2. Simulation modeling and description

Fig. 1 demonstrates the simulation model of a dispersion-managed soliton regime in a long-haul optical fiber link. It represents the circulating loop setup, where each loop consists of six regular fiber spans, one DCF span inserted non-symmetrically in the beginning, middle and end of the fiber loop, optical filter and seven optical amplifiers (EDFAs), with total loop length of 180 km. Soliton pulses travel through total 100 loops or transmission length up to 18,000 km. Fibers in a loop are 30-km long with dispersion coefficient 0.2 ps/km nm at 1550 nm and dispersion slope 0.07 ps/km/nm^2. For six spans total accumulated dispersion is 36 ps/nm. DCF has dispersion −72 ps/km nm and length 0.5 km, i.e. total dispersion is −36 ps/nm and that fully compensates the cumulative dispersion in the loop to zero. Here DCF is inserted non-symmetrically, thus a non-zero anomalous dispersion equal to 6 ps/nm is maintained by inserting DCF in the beginning, middle and end of the fiber loop. Non-zero local dispersion helps to reduce FWM penalties.

Modern WDM lightwave systems employ dispersion management to compensate for cumulative dispersion and to suppress FWM penalties. Fiber loss is 0.22 dB/km and EDFAs after fiber span are set to 6.6 dB gain to compensate signal attenuation. The optical filter is placed at the end of the loop and has a width of 2.7 nm.

The input pulse is generated by a mode-locked laser and has a “sech” shape with 7 ps pulse width. The pulse peak power corresponds to $N = 1$ soliton and is set to be 11.56 mW. Property map block tapped to outputs of elements in the loop will record pulse dispersion, width and optical power along the fiber length.

3. Results and discussions

Fig. 2 shows the dispersion map of the optical transmission link for mid-compensated soliton transmission, which shows the dispersion accumulation along the fiber length. In each loop, the dispersion is compensated back to zero, but since DCF is inserted non-symmetrically in the beginning, middle and end of the fiber loop, the average dispersion is small but non-zero, equal to 6 ps/nm. Fig. 3 shows the pulse width evolution. Along the fiber length the FWHM starts at 7 ps, then oscillates and reaches up to the width of 32 ps, and after about 10,000 km converges to steady state with pulse width changing periodically between 6 and 13 ps within each loop.

In case of mid-compensated optical soliton propagation, the input soliton pulse first travels 60 km (two fiber spans of 30 km each) of anomalous dispersion fiber supporting soliton propagation, but then DCF nonlinearity broadens the soliton pulse into a rectangular pulse with a linear chirp. This up-chirped pulse is coupled into next 30 km long fibers with anomalous dispersion. Because the pulse after passing through first 60 km is up-chirped and broadened, the pulse is linearly

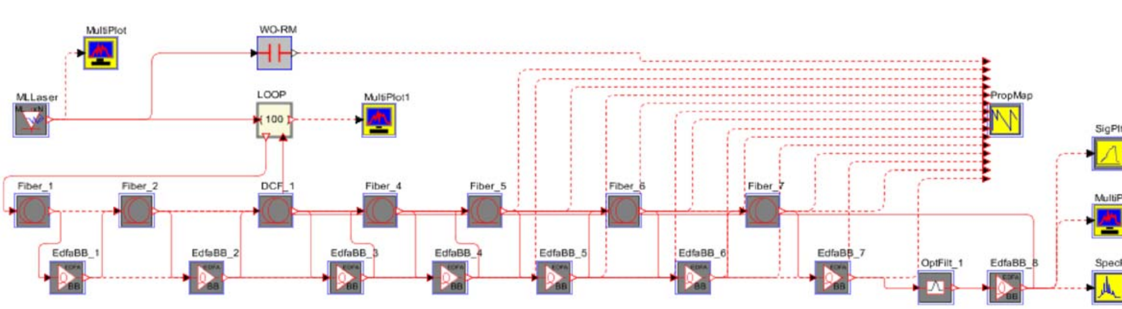

Fig. 1. Layout for pre-, post- and mid-compensated dispersion-managed soliton regime in a fiber link.

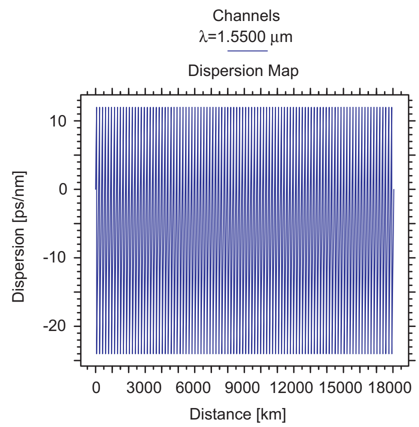

Fig. 2. Dispersion evolution along the fiber length for mid-compensated soliton transmission.

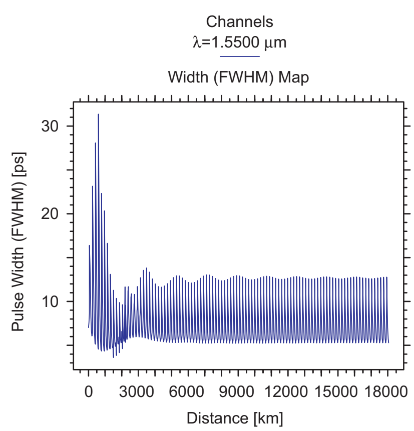

Fig. 3. Pulse width evolution along the fiber length for mid-compensated soliton transmission.

compressed by the anomalous dispersion and a high-order soliton is excited in the next 180 km fiber. This results in large spectral broadening and soliton narrowing. Fig. 4 shows overlaid dispersion map plot with pulse width plot mid-compensated soliton transmission. It is observed that pulse is narrowing in anomalous dispersion fiber and broadening at DCF. When the pulse spectrum is broadening due to the higher-order soliton effect and third-order dispersion near the zero dispersion wavelength, the spectrum begins to be shaped by the 2.7 nm optical filter installed at the end of the loop. It removes the unwanted spectral peak that gets created on the left-hand side of the spectrum.

It is seen that the pulse width changes periodically even in the steady state and the pulse is not transform-limited. The chirped pulse is almost linearly compressed in the anomalous GVD fiber and becomes almost a transform-limited pulse. Fig. 5 shows the chirp of output pulse after 18,000 km for mid-compensated soliton transmission. Fig. 6 shows the pulse power evolution along the fiber length for mid-compensated

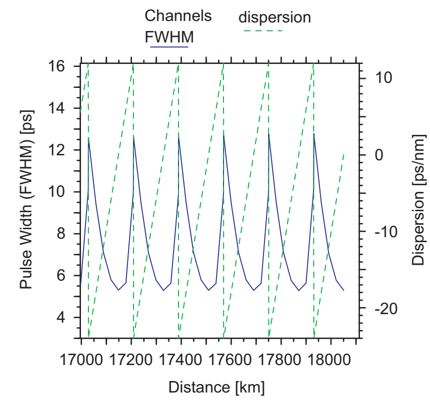

Fig. 4. Pulse width and dispersion map overlaid for mid-compensated soliton transmission.

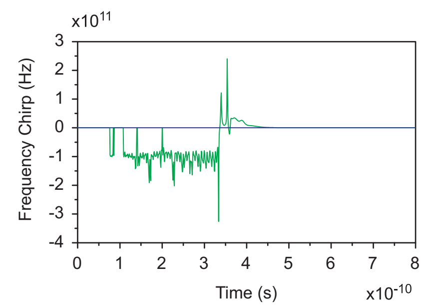

Fig. 5. Frequency chirp of output pulse after 18,000 km for mid-compensated soliton transmission.

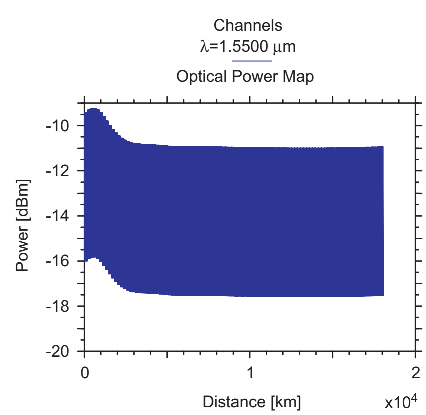

Fig. 6. Pulse power evolution along the fiber length for mid-compensated soliton transmission.

soliton transmission. After traveling a few first loops the pulse converges to quasi-steady state.

Fig. 7 gives 3D waterfall plots for waveform and spectrum for mid-compensated soliton transmission as a function of transmission distance. Here it has been observed that the optical soliton pulses regain their shape and maintain the pulse broadening with slight change in frequency. Figs. 8 and 10 give 3D waterfall plot for waveform and spectrum for pre- and post-compensated

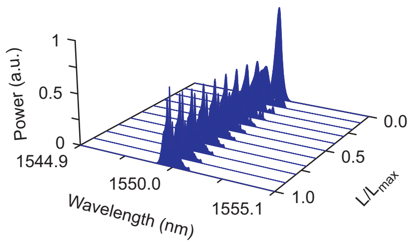

Fig. 7. 3-D plot for mid-compensated soliton evolution along the fiber length.

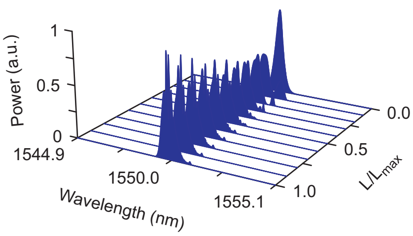

Fig. 8. 3-D plot for pre-compensated soliton evolution along the fiber length.

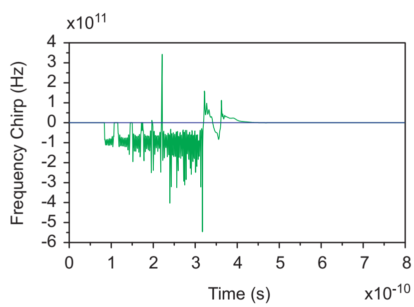

Fig. 9. Frequency chirp of output pulse after 18,000 km for pre-compensated soliton transmission.

soliton transmission as a function of transmission distance. Figs. 9 and 10 show the chirp of output pulse after 18,000 km for pre- and post-compensated soliton transmission (Fig. 11). Fig. 12 shows pulse waveform and corresponding spectrum for input and output pulse after 100 loops for pre-, mid- and post-compensated soliton transmission. It is richly evident from Fig. 12 that pulse evolution in a mid-compensated soliton transmission technique is better than the pre- and post-compensated schemes. This is because in case of mid-compensated scheme, a differential time delay between input and output soliton pulses of 0.55 ps is obtained after a transmission distance of 18,000 km. However the soliton output pulse is able to maintain its width and signal amplitude with marginal decrease. Pre-compensation decreases the signal power due to the higher attenuation of DCF, and signal experiences normal dispersion while the signal power is higher; whereas in the post-compensation, the signal power falls more slowly in SMF and experiences anomalous dispersion while the

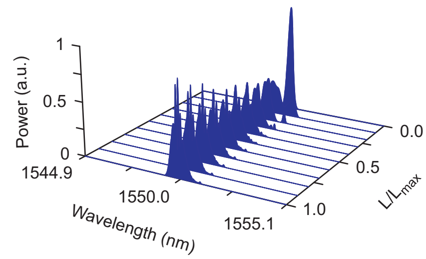

Fig. 10. 3-D plot for post-compensated soliton evolution along the fiber length.

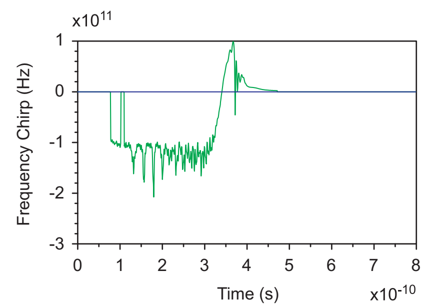

Fig. 11. Frequency chirp of output pulse after 18,000 km for post-compensated soliton.

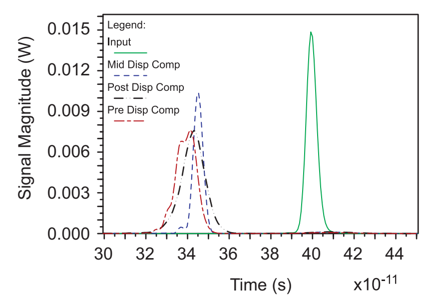

Fig. 12. Input and output (after 18,000 km) optical spectra for pre-, mid- and post-compensated soliton transmission.

signal power is higher. Pre-compensation has also been shown to result in increased pulse compression due to self-phase modulation, as compared to the more detrimental pulse broadening effect that occurs in post-compensation. Due to the interplay between dispersion, nonlinearities and signal power, the dispersion map strongly affects the pulse evolution in the link.

4. Conclusions

In this paper, the results have been reported for improved performance analysis by positioning the DCF non-symmetrically in a periodic amplified re-circulating loop for optical soliton transmission link over a long-haul transmission distance of 18,000 km. It has been shown that the dispersion compensation is achieved through soliton pulse narrowing in anomalous dispersion fiber and broadening at DCF. In conclusion, the pulse propagation in mid-dispersion-compensated soliton transmission link reveals improvement in performance over pre- and post-compensated schemes and is similar to conventional transform-limited soliton transmission link.

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