Transmission improvement in grating-compensated dispersion-managed soliton systems using nonlinear optical loop mirrors

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Abstract

We show that the system performance can be substantially improved by the use of nonlinear optical loop mirrors in lossy dispersion-managed soliton systems compensated by chirped fiber gratings with group delay ripples.

In optical fiber communications, the most successful technique to minimize the effect of chromatic dispersion is dispersion management. Among the many different dispersion compensating methods, the use of chirped fiber gratings (CFGs) is an effective one because of its compact size and large lumped dispersion. Chirped fiber gratings also can compensate higher order dispersion, have low insertion loss, and no nonlinear effects. It has been shown that solitons exist in dispersion-managed (DM) communication systems compensated by CFGs [1, 2]. Yamada et al. demonstrated transmission over 2.900 km for return-to-zero (RZ) formatted signals utilizing CFGs as dispersion compensator at 10 Gb/s [3].

In real CFGs, there are fluctuations in the group delay known as group delay ripples (GDR) which is caused by the imperfections in the grating fabrication process. The GDR introduce side peaks in the pulse profile as shown in Fig. 1(a) and lead to intersymbol interference (ISI). In linear systems, the amplitudes of these side peaks grow linearly with the number of CFGs along the propagation distance [4] and thus degrade the transmission performance. We have shown that soliton transmission, unlike in linear systems, can suppress the growth of these side peaks [2]. The side peaks however still exist and may cause ISI. It was proposed and demonstrated that nonlinear optical loop mirror (NOLM) can be used for 2R regeneration in RZ-DM transmission systems utilizing dispersion compensating fibers [5, 6]. We have also shown that NOLMs can also be used to significantly reduce the side peaks in lossless grating-compensated DM soliton systems [7].

In this work, we investigate the reduction of side peaks by NOLMs in grating-compensated DM soliton systems when loss and gain are taken into account. We numerically obtained the stable solutions in the lossy systems with NOLMs and showed that the side peaks in the solutions are significantly reduced. We also demonstrated that the transmission distance could be improved by twenty times using NOLMs even if the central peak of neighboring pulses is located at the first side peaks of the corresponding pulse, an arrangement for maximum ISI.

![Temporal pulse shapes in the lossy grating-compensated DM soliton systems with group delay ripples](image)

Figure 1: Temporal pulse shapes in the lossy grating-compensated DM soliton systems with group delay ripples: (a) without NOLMs; (b) with NOLMs.

In DM soliton systems, the pulse dynamics in optical fibers with dispersion and Kerr effects is modeled by the nonlinear Schrödinger equation. In real gratings, the structure of the GDR is rather complex and depends on factors such as the apodization profile, the grating length, etc. For simplicity, we model the GDR by a sinusoidal function [2].

The DM soliton system we studied consists of 40 km of a segment of fiber and a CFG. The dispersion, nonlinearity, and loss coefficient of fibers are 1.06 ps/nm/km, 2 km⁻¹W⁻¹, and 0.2 dB/km, respectively. The average lumped dispersion of the
The intensity (solid line) and timing (inset) Q-factors versus propagation distance in the lossy grating-compensated DM soliton systems without NOLMs.

We numerically determine the stable solutions in the lossy DM soliton systems with and without the NOLMs. The pulse parameters with and without the NOLMs are different because of the extra nonlinearity introduced by the NOLMs. We compare the DM soliton solutions with and without the same pulse width for the two cases; 5.9 ps without NOLMs and 4.8 ps with NOLMs. The pulse width is the full width at half maximum intensity width measured just after the amplifier location. Figures 1(a) and (b) show the temporal profiles of the stable solutions in the systems without and with NOLMs, respectively. Without NOLMs, the pulse width decreases as energy increases and 5.9 ps is the minimum pulse width that have a stable numerical solution. With the NOLMs, we find that the minimum pulse width increases slightly as energy increases and 4.8 ps is the largest numerically stable pulse width for this choice of system parameters. The pulse energy for the system with NOLMs is twice that without NOLMs, but the power of the first side peaks is reduced by ~57 dB.

We examine transmission of the bit pattern 01111010110100100 in systems without and with NOLMs. We choose the bit window to be equal to the side peak separation such that the central peak of a pulse overlap with the side peaks of its neighboring pulses which will result in maximum pulse-pulse interaction. Figure 2 shows the intensity Q-factor (solid line) along the propagation distance without NOLMs in the system. The timing Q-factor is shown in the inset for reference. Figure 3 shows the timing Q-factor (dashed line) along the propagation distance for systems with NOLMs. The intensity Q-factor is shown in the inset. The value $Q = 6$ (dotted line) corresponds to a bit-error-rate of $10^{-9}$. The propagation distance for error-free transmission for systems with NOLMs is 7,480 km which is 20 times longer than that without NOLMs, i.e. 360 km. Without the NOLMs, energy exchange between the central and the side peaks of the pulses reduce the intensity Q-factor. The NOLMs reduce the side peaks thus significantly enhance the intensity Q-factor.

In summary, we have shown that soliton solutions exist in lossy grating-compensated DM soliton system using NOLMs. The use of NOLMs significantly improve the transmission distance.

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References