Analytical Method for Designing Grating Compensated Dispersion-Managed Soliton Systems

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Abstract

We show a useful analytical method to design grating compensated dispersion-managed systems. Our method is in good agreement with the numerical results even in the presence of group delay ripples in the chirped fiber gratings.

1 Introduction

Among the many different dispersion compensating methods, the use of chirped fiber gratings (CFGs) is an effective one because of its compact size. It has been shown that solitons exist in dispersion-managed (DM) systems utilizing CFGs for dispersion compensation [1]. There are no analytical methods to find soliton solutions in DM systems compensated by CFGs. A numerical averaging method, developed by Nijhof et al. [2], is the commonly used technique to find the soliton solutions in DM soliton systems. It is difficult, to use this method to obtain a stable solution for the desired pulse width and energy simultaneously. System engineers, however, are interested to design DM soliton systems for a given bit rate (hence the pulse width) and initial pulse energy. We can use the averaging algorithm to perform a massive study in map design. The process however, can be time consuming.

In this work, we present an efficient method to obtain the map design for a given Gaussian pulse energy and width in DM soliton communication systems compensated by CFG. We show that the results from our analytical method are in good agreement with those obtained using the numerical averaging method.

2 Analytical method

The dispersion map contains a fiber segment and a CFG. The gratings are located at the middle of the fiber segments and their actions are a lumped function. The CFGs have group delay ripples (GDR) which are the result of imperfections formed during fabrication of the gratings. The ripple period of the GDR in CFGs is much shorter than the signal bandwidth. We, therefore, neglect the effect of ripples in the following analysis. Using the variational analysis with Gaussian ansatz in the nonlinear Schrödinger equation, for any given minimum ($x_{\min}$) and maximum ($x_{\max}$) pulse widths and pulse energy ($E_0$), we obtain the map length as

$$L = 2G - \left[ \gamma \beta E_0 \ln(4c_0 - 2\sqrt{2\gamma E_0}) \right] / (c\sqrt{c})$$

where

$$G = \sqrt{cR + \gamma E_0 \ln(2\sqrt{2cR} + 4c_0 - 2\sqrt{2\gamma E_0})} / (2c\sqrt{c})$$

$$R = 2c_0 x_{\min}^2 - 2\sqrt{2\gamma E_0} x_{\max} - 4\beta^2$$

$$c = 2\beta^2 / x_{\min}^2 + \sqrt{2\gamma E_0} / x_{\min}$$

The parameter $\beta$ is the group velocity dispersion and $\gamma$ is the Kerr coefficient. The required grating dispersion is $g = 2x_{\min}^2 x_{\max}^2 / (4 + x_{\min}^2 x_{\max}^2)$, where

$$x_{\min} = -\sqrt{4\beta^2 / x_{\min}^2 - 2\sqrt{2\gamma E_0} / x_{\max} + 2c / (\beta x_{\max})}$$

We compare our analytic results with the results from the averaging method. We consider a fiber dispersion of 1 ps/km/nm, nonlinearity of 2 km$^{-1}$W$^{-1}$, and input width of 5 ps and analytically calculated the map length and grating dispersion values. Figure 1 shows the input FWHM of the numerical results obtained for different energies and map strengths $S$ of 1.65 (solid curve) and 3 (dashed curve) represent the case without GDR in the gratings. It shows that the numerical results are close to the assumed input pulse width 5 ps in the analytically designed CFG compensated DM soliton systems.
The CFG, however, have GDR which are induced during the grating manufacturing processes and it will cause side peaks in the pulse temporal profile as shown in Fig. 2. Since the total energy in the side peaks is much less than that in the central peak of the pulse, the significance of the side peaks is very small \(^1\). Thus we have not included the effect of GDR in our analytical design. In order to show the usefulness of our method, we apply our analytical method to the DM soliton systems with GDR in gratings. We consider a sinusoidal form of GDR with amplitude 5 ps and period 0.064 nm in the gratings of the analytically designed DM soliton systems in Fig. 1. In general, the structure of the GDR in CFG is quite complex. Hence for simplicity here we use sinusoidal form of GDR in all the simulations which involve GDR in gratings \(^1\). We launch the same Gaussian pulses as above in the analytically designed systems with GDR in gratings and obtain the DM soliton solutions by the numerical averaging method. Figure 3 represents the numerical results for map strength of 1.65 (solid curve) and 3 (dashed curve) in the case with GDR in the gratings. The numerical results in the case of gratings with GDR are very close to the ideal one. It can be seen that the pulse widths of the numerical soliton solution is around the initially assumed value 5 ps for analytically designed DM soliton systems with GDR. It shows that our analytical method is also useful to design DM soliton systems even in the presence of GDR in gratings.

**Conclusion**

In summary, we have presented a complete analytical method to design grating compensated DM soliton systems. Similar idea can be used for designing DM soliton systems with loss and gain. We have shown that our design can be applied for gratings with GDR.

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**References**