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HIGH SPEED OPTICAL TRANSMISSION WITH DENSE DISPERSION MANAGED SOLITON

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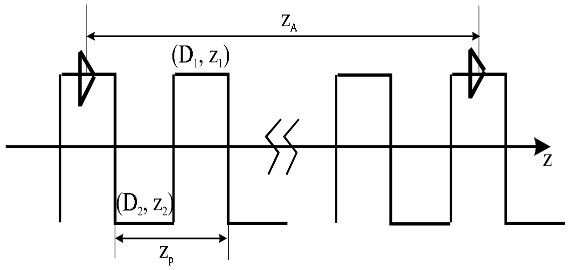
Abstract: We numerically simulate 80 Gbit/s soliton transmission in a dense periodical dispersion managed fiber. Such a soliton is generally more stable and faces less mutual interactions than a conventional dispersion managed soliton.

Introduction

In dispersion managed soliton (DMS) proposed so far, the period of dispersion management z_p is same as or longer than the amplifier spacing z_A/1, 2/. As a result, when narrower pulse is used, the pulse width oscillates with significant magnitude and induces interactions with neighboring pulses. This results in the limitation of the transmission speed. To reach the optimal dispersion map strength (DS) in ultra-high speed DMS, we must choose very low local dispersion, which requires strict dispersion tolerance. Furthermore, such a transmission line may induce large four-wave-mixing (FWM). On the other hand, when z_p is much smaller than z_A, DS becomes very small and the pulse approaches to the ideal soliton and again the interaction becomes significant due to its exponential tail/3/. Therefore, a densely dispersion managed soliton (DDMS) in a dense periodical fiber/4/ (DPF) proposed earlier, whose dispersion map is shown in Figure 1, is expected to have longer collision distance and avoid this limitation by choosing the proper number of periods $n = z_p/z_A$. In this way, one can construct a system having an optimum collision distance with a reasonable value of local dispersion and power enhancement factor (PEF)/5/.

Figure 1: Dispersion map of a dense periodical dispersion managed fiber.

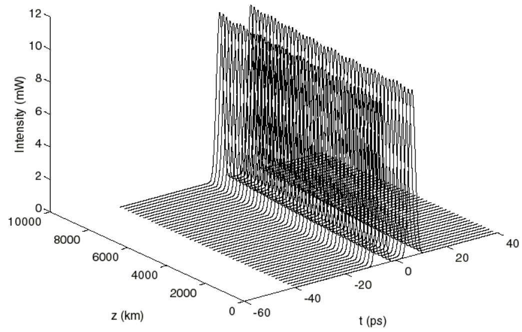


80 Gbit/s Soliton Transmission in dense periodical fiber

Numerical simulations of DDMS propagation are carried out. In the simulations, Kerr nonlinearity, loss of fibers, Raman effect, and second and third order dispersions are taken into account. We use dispersion slope compensation in the DPF to reduce the influence of the *average* third order dispersion. The parameters we used are z_A = 40 km, n = 9, $D_1 = - D_2$ = 2.5 ps/nm/km, $S_1 = - S_2$ = 0.07 ps/nm^2/km, D_{ave} = 0.01 ps/nm/km, α = 0.2 dB/km, γ = 2.59 rad/W/km, T_R = 3 fs, where D_1, D_2 and S_1, S_2 are dispersion parameters and dispersion slopes of the fiber 1 and 2 shown in Figure 1, D_{ave}, α, γ, T_R are average dispersion parameter, loss, nonlinear coefficient, and delay of the Raman response of the DPF, respectively. The stable solution of soliton is obtained by the average method/6/. Figure 2 shows a pair of DDMS pulses with the separation of 12.5 ps, which corresponds to 80 Gbit/s, transmit over 9,000 km. The FWHM pulse widths t_{FWHM} are 2.93 ps. Here the DS is chosen to optimum value of DS, s = 1.65, found by Yu et al /5/ in loss-less conventional dispersion management. The power $P_{00} = - k''_{ave}/\gamma t_o^2$, where t_0 is the normalizing factor of time, is 1.78 mW and the power enhancement factor PEF of 2.61 is 89.7 % of 2.91, which is calculated from the Nijhof et al's formula/6/. Relative large timing shift and intensity fluctuation comes from intra pulse Raman effect (IPRE). This intensity fluctuation may induce serious timing jitter of transmitted solitons because the timing shift due to IPRE is, in first order, proportional to the fourth power of the soliton amplitude according to the conventional soliton theory.

Figure 2: Transmission of a pair of DDMS with 12.5 ps separation over 9,000 km.

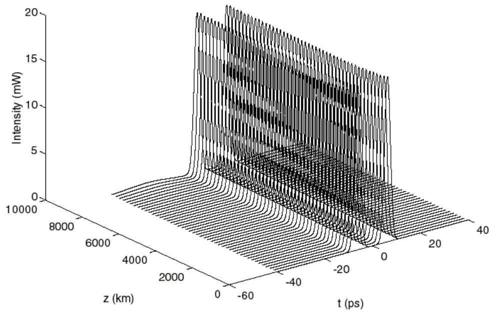
Next, we investigate DDMS propagation in a DPF with



distributed bandpass filter. Figure 3 shows a pair of DDMS pulses, whose pulse widths t_{FWHM} are 2.87 ps. The bandwidth of the filter at normalized distance is 2.57 THz which is 35.3 times of RMS bandwidth of the soliton Δf_{RMS} = 72.6 GHz. In this case, the amplitude fluctuation and the peak shift are reduced significantly by filters. $P_{00} = 1.85$ mW which corresponds to the PEF of 4.41 is 1.44 times larger than the calculated value 3.07. The excess gain is 0.790 Mm^{-1}, which induces only 1.07 times power enhancement. The IPRE frequency shift of 8.50-8.57 GHz also induces only 1.000003 power enhancement due to the filter. At this moment, it is not clear why the PEF in DPF with filter is larger than the calculated value. The RMS chirp/7/ of the DDMS is 31.5 GHz which is 43.4 % of Δf_{RMS}.

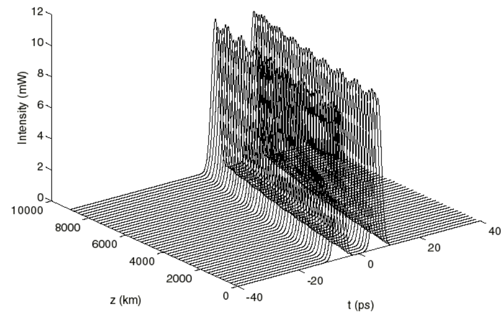
For 80 Gbit/s soliton systems, the required variation of the timing jitter $<\delta t^2>$ is less than 0.51 ps^2/8/ for BER $< 10^{-9}$. If spontaneous emission factor of the EDFA's n_{sp} = 1.2, D_{ave} = 0.01 ps/nm/km, and t_{FWHM} = 2.87 ps, we have $<\delta t^2>$ = 15.5 ps^2 due to the Gordon-Haus effect/9/ without considering the filtering effect and PEF. If we roughly estimate the timing jitter by considering the effects of filter (according to the conventional timing jitter reduction theory by the filter) and the PEF/10/, we have $<\delta t^2> <$ 0.052 ps^2 which is much smaller than 0.51 ps^2. In order to study the tolerance of the systems, we made a simulation with D_{ave} of 0.02 ps/nm/km. The result showed that both the timing shift and the intensity fluctuation did not increase so much, although the peak power was about two times higher than that in D_{ave} of 0.01 ps/nm/km.

Figure 3: Transmission of a pair of DDMS in a bandwidth limited DPF.



In a DMS (i.e. n=1) with the same local dispersion as in Figure 2, even if we do not consider the *local* third order dispersion and the IPRE, we can not find the stable pair of pulses whose t_{FWHM} are narrower than 5 ps. For the 3 ps pulse in the DMS, the DS s = 14.2 is too strong to allow the stable soliton transmission/11/. Even if there were stable solution for a single pulse in the DMS, the soliton interaction would be quite large because of serious overlap. For comparison, the behavior of DMS with similar DS (s = 1.62) but lower local dispersion (D_1 = - D_2 = 0.26 ps/nm/km) without filter is shown in Figure 4. The local third order dispersion and the IPRE are taken into account. At 9, 000 km, the pulse position shift induced by IPRE is as large as 14.1 ps which is 2.61 times larger than that of Figure 2, and the intensity fluctuation of 7.5% is 3.6 times larger. The IPRE in DMS with lower local dispersion is much more serious than those in DDMS with higher local dispersion, since the walk off of the pump wave from the Stokes wave is smaller in the DMS than that in the DDMS. We also note that the background dispersive waves in the DMS are about 20 dB higher than that in the DDMS.

Figure 4: Transmission of a pair of DMS without filter.



In addition to the above merits, DDMS is shown to have much smaller FWM than DMS over a broad wavelength range/12/. Moreover, if DDMS is applied to local fiber networks, we can add a new node or drop an old node at any position with the integral of dispersion periods in DPF. Therefore fiber networks using DDMS can be reconfigured easier than those using DMS.

Conclusion

We found that high speed DDMS with low soliton interaction can transmit in optimal DPF with higher local dispersion and dispersion slope compensation. In addition to reducing timing jitter and soliton interaction in dispersion managed soliton systems, we found filters can also reduce the influence of IPRE as in the case of conventional soliton/13/. As an example, 80 Gbit/s DDMS can be transmitted over 9,000 km in optimal DPF with filters. Future work includes evaluation of the influence of PMD.

references

/1/ M. Suzuki, I. Morita, N. Edagawa, S. Yamamoto, H. Taga, and S. Akiba, Electron. Lett., **31**, 2027 (1995).

/2/ N. J. Smith, F. M. Knox, N. J. Doran, K. J. Blow, and I. Bennion, Electron. Lett., **32**, 54 (1996).

/3/ A. Hasegawa, Y. Kodama, and A. Maruta, Opt. Fiber Tech. **3**, 197 (1997).

/4/ A. H. Liang, Appl. Opt., **36**, 3793 (1997).

/5/ T. Yu, E. A. Golovchenko, A. N. Pilipetskii, and C. R. Menyuk, Opt. Lett., **22**, 793 (1997).

/6/ J. H. B. Nijhof, N. J. Doran, and W. Forysiak, OFC'98 (San Jose), THC4, 268 (1998).

/7/ A. H. Liang, H. K. Tsang, and L. Y. Chan, IEEE J. Quantum Electron., **32**, 2064 (1996).

/8/ L. F. Mollenauer, J. P. Gordon, and M. N. Islam, IEEE J. Quantum Electron., **22**, 157 (1986).

/9/ J. P. Gordon and H. A. Haus, Opt. Lett., **11**, 665 (1986).

/10/ N. J. Smith, N. J. Doran, W. Forysiak, and F. M. Knox, J. Lightwave Technol., **15**, 1808 (1997).

/11/ N. J. Doran, ECOC'98 (Madrid, Spain), 97 (1998).

/12/ A. H. Liang, H. Toda, and A. Hasegawa, submitted to Opt. Lett.

/13/ K. J. Blow, N. J. Doran, and D. Wood, J. Opt. Soc. Am. B, **5**, 1301 (1988).