Unlimited soliton propagation and noise suppression in a system with spectral filtering and saturable absorption

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Abstract
We show that soliton propagation is ultimately stable to both amplitude and frequency noise in a system employing spectral filtering and saturable absorption. In such a system, the amplification period may be increased to 3-5 dispersion lengths for 10 dB linear losses between amplifiers.
Growth of potassium lithium niobate fiber crystal and its application for blue light generation

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Potassium lithium niobate (KLN) is expected as a promising nonlinear material due to its superior optical and mechanical properties compared to potassium niobate (KNO3). A KLN single-crystal fiber has a tetragonal tungsten bronze crystal structure with a composition described by KxLi2-xNb2O5, for 0 < x < 0.5. A variation in the mole fraction of lithium leads to a wavelength for noncircular second harmonic generation (SHG) lying within the range of 790–920 nm at room temperature (RT). However, difficulties in growing noncongruently melting KLN crystal of sufficient size and of reasonable uniformity of crystal composition have remained.

In order to know the angular and temperature acceptances, the KLN seeded solution growth (TSSG) method was used. The KLN crystal used was grown by the TSSG method, using KNO3 as the seed crystal. The acceptance of the KLN crystal was evaluated by the ratio of the SHG intensity of the KLN crystal to that of the KNO3 seed.

CThN
4:30 pm

Technology for Ultrafast Systems

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It is known that the use of relatively narrow filters in soliton communication systems reduces the perturbations to the soliton amplitude and frequency permitting an increase in the propagation distance. However, such an approach requires excess gain to compensate for soliton loss at the filters, so the system is intrinsically unstable. The only solution is to use a nonlinear component and accumulation of ASE noise. Sliding filters and nonlinear gain were proposed to suppress this instability. But fabrication of sliding filters is technically complicated, and the steady-state pulse has a large chirp, so the transition to the steady state requires a large distance. The nonlinear gain may be used only in combination with excess linear gain, as otherwise the soliton tends to collapse even in the presence of filters. So in such a system, the non-soliton component growth is only decreased and the system still remains unstable. We propose the use of fast semiconductor saturable absorbers (SA) to achieve soliton stability over unlimited distances as well as a steady state pulse with low chirp.

Let us consider SA with saturation intensity \( I_s \) and peak intensity \( I_p \). Suppose that soliton peak intensity and saturation time significantly shorter than the pulse duration and a parabolic-shape filter with bandwidth \( \Omega \) in soliton bandwidths. The absorption coefficient \( \alpha \) depends on intensity \( I \) with \( \alpha(\lambda) = \alpha_0(1 + \lambda^2/\lambda_c^2) \). If the additional loss for linear radiation due to the presence of the SA is higher than additional losses for the soliton due to the presence of both SA
and filtering, then a small additional linear gain provides for stable soliton propagation, while the linear radiation is suppressed. There is a power threshold for the input pulse, below which the pulse is damped by the SA, while above threshold the stable soliton forms from the original pulse.

Computer results show that such a system allows significant improvement to the performance of solitons for communication. In particular, pulse durations may be greatly reduced such that the distance between amplifiers $Z_2$ may be equal to 3 dispersion lengths for 10 dB losses between amplifiers. Figure 1 demonstrates the pulse dynamics for a system without filtering, with filtering only, and with filtering plus SA. Without filtering the pulse is rapidly destroyed by the soliton resonance, while even optimal filtering only results in marginal improvement of the performance and the eventually growing pedestal destroys the soliton. The system with both SA and filtering gives indefinite steady-state propagation. Figure 2 shows that the steady state propagation is periodic with respect to $Z_2$ with the pulse duration changes of $\pm 30\%$. Also, the SA and filter act on the pulse chirp in opposite directions, so the steady-state pulse has low chirp and the transition to steady-state is rapid. Steady state propagation has been achieved even for $Z_2 = 5$ with 10 dB losses and $Z_2 = 1$ with 20 dB losses, although the transition to steady state is slower. Figure 3 shows the suppression of soliton interaction by the combined action of both SA and filtering.

In our calculations we have assumed an instantaneous nonlinear response of the SA, while real SAs have response times of around 200 fs. We show that the finite response time of the SA leads to an effect analogous to the soliton self-frequency shift, which can be suppressed by bandwidth-limited amplification.

In conclusion, we have found that the performance of soliton communication systems may be improved by incorporating of saturable absorption. Although the information transmission distance is limited due to the Gordon–Haus effect, the use of narrower filters with suppression of the non-soliton component allows the bit-rate to be increased, while the individual solitons remain ultimately stable.

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Phase conjugation for jitter and soliton–soliton compensation in soliton communications

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It has recently been pointed out that mid-point optical phase conjugation (OPC) can compensate for self-phase modulation in addition to linear dispersion in periodically amplified systems. Here we apply the concept to soliton communication systems. The principle is that conjugation is equivalent to "time" reversal in Nonlinear Schrödinger Equation Systems. In periodically amplified systems soliton concepts apply within the average soliton limit. Thus a mid-point conjugation will lead to a complete reversal of soliton effects provided the average soliton limit is obeyed. Figure 1 shows in particular the reversal of soliton-soliton interactions via this method after a 10,400-km system operating at 20 Gbit/s. The output is almost identical to the input with no effects from soliton-soliton interaction.

OPC has, however, a further potentially more significant beneficial effect in soliton systems, namely the reduction of Gordon–Haus jitter. The use of post-propagation dispersion compensation has recently been shown to reduce the Gordon–Haus RMS timing jitter by a factor of 2.

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Fig. 3. Suppression of soliton interaction by SA and filtering ($\Omega = 3.0$, $\alpha_0 = 0.6$).

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CThN2 Fig. 1. Mid-point phase conjugation reversing soliton-soliton interaction in a 10,400 km amplified system.