We propose a new scheme for generating a pedestal-free, femtosecond soliton pulse train by utilizing quasi-adiabatic high order soliton pulse evolution in dispersion decreasing fiber in conjunction with the intermediate pedestal suppression stage. Compression factor over 250 was achieved from 10GHz sinusoidal input, to 207fs soliton pulse train.
Design Parameters of Dispersion Decreasing Fiber based OTDM source: Quasi-adiabatic Higher-order Soliton Compression from Sinusoidal Input Signal

Duckey Lee, Na Young Kim, Kyoung Min Kim, Namkyoo Park
Optical Communication Systems Laboratory, School of Electrical Engineering, Seoul National University
Phone: +82-2-872-3577, Fax: +82-2-885-5284, E-mail: nkpark@plaza.snu.ac.kr

Seong Joon Ahn, and Hee-gon Woo
System and Communication Research Laboratory
Korea Electric Power Research Institute, Munji, Yusong, Taejon, Koewa, 305-380

1. Introduction

Optical time division multiplexed (OTDM) transmission system has been a topic of continuous research due to their unique advantages over conventional NRZ based transmissions, including the possibility of nonlinearity based all-optical information processing, and tolerances on dispersions penalties in the link. Among various key technologies which enable the successful integration of OTDM system, high repetition rate, transform limited pulse source still remains as one of the issues that require further optimization. Still, most pulse sources developed so far had one or more drawbacks to be used as an information carrier, with unavoidable problems like timing jitter, pulse dropping, or severe chirp in the pulse, inherent in their generation methods. The recently proposed pulse shaping method using Dispersion Decreasing Fiber (DDF) resolved several past issues providing high quality pulse with exact signal timing, but the application mostly has been limited to ultra-high repetition rate above 100's GHz [1]. The required DDF length to generate pulse stream at low repetition rate (~10GHz) becomes close to hundreds of km, making this approach impractical for OTDM applications [1]. The impractically long DDF length is from the adiabatic compression condition, which require DDF length for adiabatic compression in proportion to the input pulsewidth squared. For sinusoidal input signal, this makes the necessary DDF length thus to be inversely proportional to repetition rate squared.

To resolve this problem, using fundamental soliton train with relatively short pulsewidth instead of sinusoidal signal at the input section of the DDF has been suggested, making the adiabatic compression scheme applicable to low repetition rate [2]. Other method includes generation of femtosecond pulses from a short segment of DDF after a preliminary compression of higher order (N~3.5) input soliton pulse from electro-absorption modulator (EAM) in standard single mode fiber (SMF) [3]. Still, this scheme has a little disadvantage in terms of spectral purity and complexity in generating short pulses in EAM.

In this paper, we propose a new scheme for generating a pedestal-free, femtosecond soliton pulse train from sinusoidal input signal by utilizing quasi-adiabatic pulse compression in two-stage dispersion decreasing fiber, to achieve a high compression factor > 250.

2. System model and Results

The system model of the proposed idea and the pulse shapes at each stage are illustrated in figure 1. For the precise analysis of pulse propagation, the nonlinear Schrödinger equation was solved numerically using predictor-corrector method, including the higher-order effects such as third-order fiber dispersion, self-steepening and stimulated Raman scattering (SRS).

Figure 1(a–b) shows the 10GHz sinusoidal input signal at 21dBm average power evolving into the compressed pulse train with 1.76ps full width at half maximum (FWHM) pulse. The first DDF has the total length of 13.6km and linearly decreasing dispersion profile, from 10ps/nm/km at the input to 3.2ps/nm/km at the output. Note that the length of the first DDF is much shorter than that of a DDF...
required in Mamyshev’s analysis, where the sinusoidal input evolves into a fundamental soliton. In our analysis, we rather provided excessive effective amplification in the DDF so that the input sinusoidal signal could evolve into higher order soliton, instead of \( N=1 \) soliton. Remarkable compression factor (~30) from the broad input pulselwidth (~50ps) has been achieved in the first stage, from this quasi-adiabatic evolution by the self-compression effect of higher order solitons as well as the effective amplification in DDF, although the input signal was not higher order soliton but sinusoidal. Since the output pulse evolved into a higher order soliton, a broad side pedestal was observed, as can be seen in Fig. 1 (b). After this quasi-adiabatic pulse compression process, reduction of pulse pedestal (in terms of pulse peak power ratio) from ~ -10dB to ~ -30dB has been achieved with the following saturable absorber, in this case a nonlinear amplifying loop mirror (NALM).

Figure 1(c) shows the reshaped pulse train with remarkably reduced pedestals from -12.5dB to -33.7dB after the NALM. The gain of amplifier and the length of DSF used in the NALM were regulated so that the NALM switching power is equivalent to the peak power of pulse train coming out from the first stage DDF. We used the nonlinear fiber loop mirror in the mid-stage of the pulse shaping process rather than at the last stage as demonstrated in previous reports [4,5], to achieve complete pedestal removal at following DDF stages. As a result of this pre-tailoring of the pedestal from the NALM, the second stage DDF, designed for conventional adiabatic fundamental order soliton compression provided much better pulse compression ratio and pedestal reduction, reshaping the pulses from NALM into pedestal-free femtosecond solitons. Figure 1(d) illustrates the resulting output pulse obtained at the end of the whole evolution process, with 207fs pulselwidth after the transmission of second stage of DDF. The length of the DDF used in the second stage was only 500m, with the linear dispersion decreasing profile 10ps/nm/km down to 1.95ps/nm/km.

In order to provide the guidelines for designing the first DDF, we plotted in figure 2 the optimum DDF length required for the higher order adiabatic soliton generation/compression of specified pulse shape shown in Fig. 1(b). Also plotted in the figure includes the output pulselwidth from first stage of DDF, and pedestal energy as a function of effective amplification factor \( W_{\text{eff}} \), at the fixed input power of 27dBm.
Note that large effective amplification factor is advantageous for obtaining short output pulsewidth, but undesirable in terms of the pulse quality and length of required DDF, as can be seen in figure 2. The power dependencies on the pulse output values at fixed effective amplification factors are also summarized in Table 1. As shown in table 1, pedestal energy can be reduced to ~1% level by the NALM, even with the rather large pedestal energy before the NALM process. As the sinusoidal input power increases, necessary fiber length and output pulsewidth decreases, while the pulse quality is degraded. Therefore, there exist a trade-off between pulse quality, pulsewidth, and DDF length.

3. Conclusion

We have proposed a new scheme for generating a pedestal-free, femtosecond soliton pulse train from 10GHz sinusoidal input signal by deriving proper system parameters for quasi-adiabatic pulse compression in two-stage dispersion decreasing fiber. Compression factor over 250 has been achieved with a relatively simpler set-up compared to former approaches, while maintaining excellent spectral purity.

<table>
<thead>
<tr>
<th>Input Power [dBm]</th>
<th>Optimum DDF Length [km]</th>
<th>Pulse width (Pre – NALM) [ps]</th>
<th>Pulse width (After NALM) [ps]</th>
<th>Pedestal energy (Pre - NALM) [%]</th>
<th>Pedestal energy (After NALM) [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>13.6</td>
<td>1.76</td>
<td>1.32</td>
<td>46.8</td>
<td>0.43</td>
</tr>
<tr>
<td>24</td>
<td>7.6</td>
<td>1.40</td>
<td>1.07</td>
<td>56.7</td>
<td>0.99</td>
</tr>
<tr>
<td>27</td>
<td>4.8</td>
<td>0.90</td>
<td>0.68</td>
<td>68.0</td>
<td>1.73</td>
</tr>
</tbody>
</table>

4. References