Soliton extraction from a bunch of solitons resulting from pulse breakup by using a nonlinear optical loop mirror

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We numerically investigated the transmission of a bunch of solitons resulting from the breakup of pulses with duration of several tens of picoseconds (ps) through a nonlinear optical loop mirror (NOLM) and found that under some conditions an individual soliton can be extracted. The NOLM selectivity can be adjusted by the amplification of the bunch of solitons before it is launched into the NOLM. The results demonstrate that an appropriate choice of the amplification and of the NOLM loop length makes it possible to extract one fundamental soliton and to tune the soliton duration. For a particular case of 20 ps input pulses, the duration of the extracted soliton was tuned in the range between 0.23 and 0.61 ps. We believe that the suggested method can be useful for producing solitons with desirable duration. © 2009 Optical Society of America

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1. INTRODUCTION

Pulse shaping, ultrashort pulse formation, and pulse compression are the subjects of numerous theoretical and experimental investigations. The effect of picosecond (ps) pulse narrowing in an optical fiber was demonstrated for the first time by Mollenauer *et al.* [1]. It was shown that the compression mechanism is related to the periodic evolution of higher-order solitons. Such pulse evolution can be used to produce a strong pulse narrowing at the fiber output. The inherent drawback of pulse compression is that the quality of the compressed pulse is poor since it is located on a broad pedestal. Since then, many results have been reported in which the optical pulse-compression effect in fibers with anomalous dispersion was exploited [2–9]. In these papers, a lot of attention was given to the reduction of the pedestal from the compressed pulse [3–9]. The inherent proprieties of the nonlinear optical loop mirror (NOLM) make it an attractive element for optical switching, pulse formation, and pedestal removal. The operation principle of the NOLM relies on the differential nonlinear phase shift acquired by counterpropagating beams [10]. A fundamental problem of the NOLM is that complete switching occurs for only a portion of the optical pulse since the phase shift follows the intensity envelope. One way of avoiding this incomplete pulse switching is to use optical solitons, because the uniform phase shift that applies to the whole pulse makes possible the switching of the entire pulse [11–16].

Shortly after the first publication of the NOLM [10] it was suggested for pulse shaping applications [17,18]. The proposed NOLM initially exploits the differential nonlinear phase shift caused by the power difference of the counterpropagating beams in the loop. For this purpose the coupler in the NOLM has to be imbalanced. The drawback of this configuration is nonzero low-power transmission that is undesirable for pedestal removal. A dispersion-imbalanced NOLM with a 50/50 coupler was suggested [19] and discussed for pedestal suppression [20–22]. The NOLM was also used for simultaneous pulse compression and pedestal reduction [23–25]. In [23] initial pulses of several ps of duration were generated by a semiconductor laser, amplified, and launched into a slightly imbalanced NOLM. Such pulses undergo simultaneous compression and shaping in the NOLM. As a result, 250 fs wide pedestal-free optical pulses were generated. The NOLM loop included weak, controllable attenuation to permit precise control of the pulse shape. The fine optimization of both fiber length and power balance between the counterpropagating pulses in the loop was required to generate pedestal-free pulses. Reference [24] studied in detail the optimization of higher-order soliton compression in an imbalanced NOLM. With these schemes a complex optimization procedure was required to obtain pedestal-free pulses with a hyperbolic-secant envelope at the output.

A power-symmetric NOLM design using polarization asymmetry was also proposed [26]. The proposed NOLM includes highly twisted low-birefringence fiber and a quarter-wave retarder (QWR) in the loop. The purpose of the QWR is to break the polarization symmetry in order to obtain a differential phase shift between the counterpropagating beams, whereas the power symmetry allows zero low-power NOLM transmission. The strong twist causes circular birefringence and decreases undesirable residual linear birefringence [27]. It makes the NOLM more stable and insensitive to environmental conditions.

It was also shown that the twisted fiber works as an ideal fiber when the nonlinear phenomena are used [28]. The low-power transmission of the NOLM can be easily tuned in the range between 0 and 0.5 just by rotation of the QWR. Even when the low-power transmission equals 0, the critical power at which the transmission reaches the value of 1 is reasonably low. The properties of this NOLM make it very useful for pedestal suppression [29,30].

It is well known that a bunch of solitons can be formed as a result of wave breakup when a high-intensity wave propagates through a fiber with anomalous dispersion [31]. The wave breakup of cw and long pulses is studied intensively in connection with the generation of a supercontinuum (see [32] and references therein). Initially, the pulse breaks up into solitons mainly because of the combination of positive Kerr nonlinearity and anomalous dispersion. Zakharov and Shabat investigated the nonlinear Schrödinger equation (NLSE) [33] and found the power distribution to which the solitons tend asymptotically in the final step of the process. From these results, in particular, it follows that the power of the highest soliton generated during the pulse breakup process is approximately four times higher than the power of the input pulse. This result presents good approximation for large variety of the flat input pulses with a big soliton number. However, the formation of solitons can be affected by soliton collisions, which lead in the presence of intrapulse Raman scattering (IRS) to the red shift of solitons and to the amplification of red-shifted solitons [34–36]. The experimental investigations with ns long pulses showed that in the initial stage the spectrum of the bunch of solitons corroborates reasonably well the prediction of the model discussed in [33] (see [37]). These results show that using the appropriate power level for the input pulse, we can obtain a bunch of solitons in which the highest soliton has the desired power and consequently the desired duration.

In this paper we numerically investigate the extraction of a single soliton from the bunch of solitons generated by the pulse breakup. For soliton extraction we use a power-symmetric NOLM with polarization asymmetry. In previous papers this NOLM design has shown good results for pulse-shaping applications when the effect of the group-velocity dispersion (GVD) is negligible. In this work the NOLM is used for the extraction of ps and sub-ps pulses. We observed that the transmission of a soliton through the NOLM depends strongly on the soliton duration, and its transmission characteristics can be adjusted by some additional amplification of the bunch of solitons before it is launched to the NOLM. It allows the extraction of one single soliton from the bunch of solitons. The optimal length of the NOLM loop depends on the duration of the soliton that we desire to extract. The numerical calculations show that the optimal loop length has to be equal to 5.7 times the dispersion length (L_D) of the desired soliton. As a particular case we used an initial pump pulse with a duration of 20 ps and peak power of 10 W. For the NOLM loop we choose a 37 m fiber. The numerical results show that with this configuration, it is possible to extract fundamental solitons with full width at half-maximum (FWHM) duration (T_{FWHM}) ranging from 0.23 to 0.61 ps. We believe that the suggested method can be very useful for producing solitons with desirable duration.

2. CONFIGURATION UNDER DISCUSSION AND CALCULATION PROCEDURE

The configuration under study is depicted in Fig. 1. Fiber 1 is pumped by an input Gaussian pulse of various ps of duration in the anomalous dispersion regime where modulation instability (MI) causes the breakup of the pump and leads to the formation of a bunch of solitons. Finally, IRS contributes to spectral broadening. According to [37], after propagation through some initial part of fiber, the soliton bunch corresponds to the results of [33] and IRS does not play an important role yet. Thus the input pulse power and the length of Fiber 1 were chosen in such a way as to have at the fiber output a soliton bunch approximately corresponding to the end of the initial stage of soliton formation. Under this condition the resulting solitons do not separate well by propagation and remain inside the initial pulse. Thus the resulting solitons are close spatially and also have close wavelengths. In calculations we used a linearly polarized 10 W Gaussian pulse with T_{FWHM} equal to 20 ps and 1.1 km Fiber 1. The fiber dispersion is 20 ps/(nm−km) at 1550 nm, and its effective mode area is equal to 81 $\mu\mathrm{m}^2$. These parameters correspond to the Corning SMF-28 fiber. The soliton number N, defined as the square root of the ratio between the dispersion and nonlinear lengths [31], is estimated as 13.5 for the input pulse. The resulting bunch of solitons coming out of Fiber 1 goes through the polarization controller (PC) to convert its polarization state into circular state. Then the pulses are amplified by an erbium-doped fiber amplifier (EDFA) and launched into the NOLM. An additional Fiber 2 may be connected at the NOLM output. This fiber allows the increase of the contrast between the highest pulse and next one.

The NOLM consists of a symmetrical coupler, a loop with highly twisted low-birefringence fiber (Corning SMF-28), and a QWR located asymmetrically in the loop, which can be rotated in a plane perpendicular to the fiber. We consider a fiber twist equal to six turns per meter. The loop length is chosen equal to 37 m. With this length the NOLM has maximum transmission for the desired soliton. It will be discussed in detail later. One important property of the NOLM in this configuration is that the transmission can be adjusted very easily. The transmission can be modified in terms of the ratio between the maximum and minimum values (contrast) or in terms of the critical power (the power necessary to produce a nonlinear phase difference of π) through adjustments of the QWR and the polarization state at the NOLM input. For the particular case of circular input polarization, the contrast can be set to any value between 1 and ∞ by manually

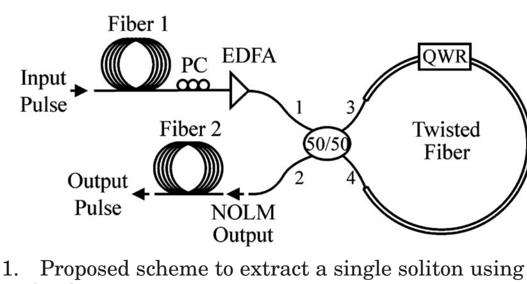

Fig. 1. Proposed scheme to extract a single soliton using a symmetrical NOLM.

rotating the QWR without change of critical power [38]. For this reason the bunch of solitons at the end of Fiber 1 is converted into a circularly polarized beam. The waveform at the NOLM output strongly depends on the gain of the amplifier inserted at the NOLM input. In our calculations we changed the amplification in a range between 1.5 and 7.5.

The principle of the NOLM operation can be described as follows. The soliton bunch with circular polarization is launched into port 1, where the symmetrical fiber coupler splits the beam into two beams of equal amplitudes transmitted through ports 3 and 4 to the loop. The coupler does not affect the polarization state, so the beam transmitted through port 3 at the beginning of its propagation is converted into a linearly polarized beam by the QWR and propagates clockwise around the loop until it reaches port 4. We model the linearly polarized beam as composed by the sum of two circularly polarized components and calculate its evolution using the circular polarization basis for our computations [see Eqs. (1)]. The counterclockwise beam propagates around the loop, maintaining its initial circular polarization. We calculate its evolution with the same Eqs. (1) taking the initial condition $A_{-}=0$. After passing through the QWR it converts its polarization state into linear and reaches port 3. Finally, linearly polarized beams are recombined in the coupler. The NOLM transmission depends both on the nonlinear phase difference and on the mutual polarization orientation of the beams. The mutual polarization of the beams depends on the QWR orientation. For calculations we used coupled-wave equations in the following form [39]:

$$\frac{\partial A_{+}}{\partial z}=\frac{\Delta\beta}{2}\frac{\partial A_{+}}{\partial T}-i\frac{\beta_2}{2}\frac{\partial^2 A_{+}}{\partial T}+i\frac{2}{3}\gamma(|A_{+}|^2+2|A_{-}|^2)A_{+},$$

$$\frac{\partial A_{-}}{\partial z}=-\frac{\Delta\beta}{2}\frac{\partial A_{-}}{\partial T}-i\frac{\beta_2}{2}\frac{\partial^2 A_{-}}{\partial T}+i\frac{2}{3}\gamma(|A_{-}|^2+2|A_{+}|^2)A_{-}, \tag{1}$$

where A_{+} and A_{-} represent the pulse envelope in the right- and left-circularly polarized states respectively; z represents the physical distance; the parameter $\Delta\beta$ represents the difference in group velocities between the left- and right-circularly polarized components; β_2 is the GVD parameter equal to $-25.5\ \mathrm{ps}^2/\mathrm{km}$ that corresponds to a dispersion parameter D of 20 ps/(nm−km) at 1550 nm; T represents the physical time in the retarded frame, and γ is the nonlinear coefficient equal to $1.621\ \mathrm{W}^{-1}/\mathrm{km}$ obtained from the effective area of 81 $\mu\mathrm{m}^2$ and the nonlinear coefficient $n_2=3.2\times10^{-20}\ \mathrm{m}^2/\mathrm{W}$ for a standard silica fiber. Equations (1) are solved numerically with the split-step Fourier method. For the NOLM calculation we simplify our treatment by excluding the Raman term, because its contribution is negligible due to the short length of the NOLM loop. However, to simulate the pulse evolution in Fiber 1 and Fiber 2, we include the Raman term in the NLSE. The modified NLSE takes the form [40]:

$$\frac{\partial A}{\partial z}+i\frac{\beta_2}{2}\frac{\partial^2 A}{\partial T}=i\gamma\left(|A|^2A-T_{\mathrm{R}}A\frac{\partial|A|^2}{\partial T}\right), \tag{2}$$

where A represents the pulse envelope, and T_{R} is the response time of the Raman effect. We used the value of T_{R} equal to 3 fs, a typical value for silica fibers [31].

3. SOLITON TRANSMISSION THROUGH THE NOLM

Suppose that fundamental solitons exit from the end of Fiber 1. They pass through the PC and convert its polarization state into circular polarization. At this point the pulses are not solitons because the amplitude of circularly polarized solitons has to be higher by a factor of 1.5. Then the pulse entering the coupler is split into two beams of equal amplitudes transmitted through ports 3 and 4 to the NOLM loop. In order to obtain soliton propagation in the NOLM loop, the pulses after the PC are amplified by the EDFA. For an amplification of 3 times, the counterclockwise pulse propagates as a fundamental circularly polarized soliton, whereas the clockwise pulse forms the coupled state of two circularly polarized pulses and suffers some compression in the NOLM loop. For an amplification of 2 times, the clockwise pulse has power corresponding to the linearly polarized soliton; however, the circular birefringence complicates the pulse evolution, and the pulse propagates in the loop as two coupled left- and right-polarized pulses. The counterclockwise pulse has an amplitude corresponding to a soliton number $N=0.81$ and undergoes dispersive effects. Figure 2 shows how the NOLM transmission depends on the soliton duration at the end of Fiber 1 for various values of amplification of the EDFA. The NOLM configuration consists of a 37 m fiber in the loop. Our calculations have shown that for an amplification of 3, the transmission calculated as the ratio between the output and input energies can reach 99.4% when the loop length and the soliton duration are appropriately adjusted. In this case the maximum transmission is reached for the soliton duration equal to 0.72 ps. The transmission never reaches 99.4% for other values of the amplification; however, it can be sufficiently high. For an amplification equal to 2, the maximum transmission reaches 94.8% at the soliton duration of 0.52 ps. For all values of amplification shown in Fig. 2, the maximum transmission is higher than 85% for amplification values ranging from 1.5 to 7.5.

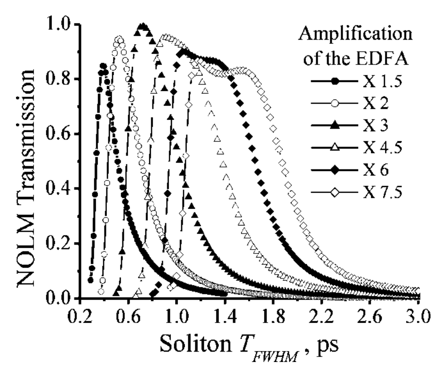

Fig. 2. Transmission of solitons through the 37 m NOLM.

As we can see, the dependence of the transmission on the soliton duration is very steep and can be changed just by adjusting the amplification of the amplifier. The maximum of the transmission moves toward longer solitons when the amplification grows. For an amplification of 1.5, the maximum transmission occurs for a soliton duration of 0.39 ps, and for an amplification of 7.5, the maximum is at 1.17 ps. The results shown in Fig. 2 suggest that the best performance can be obtained with an amplification of about 3. For lower values of amplification the pulses suffer strong dispersive effects that degrade the transmission, causing low NOLM transmission.

It can be noted that at the amplification of 3, the maximum of the transmission corresponds to the loop length of $2\pi L_D$ for optical pulses that are not significant affected by the dispersion:

$$T = (\alpha - 1)^2 + \alpha^2 - 2\alpha(1-\alpha)\cos\left[\alpha\frac{L}{L_{NL}} - (1-\alpha)\frac{L}{L_{NLC}}\right], \tag{3}$$

where L is the loop length; L_{NL} and L_{NLC} are the nonlinear lengths defined as $L_{NL}=(\gamma P_0)^{-1}$ and $L_{NLC}=1.5L_{NL}$ for the clockwise and counterclockwise propagating pulses, respectively; P_0 represents the peak power; and α represents the coupling constant of the coupler, $\alpha=0.5$ in our case. A nonlinear phase shift of π is necessary to obtain the maximum transmission. In our case, since the counterclockwise pulse propagates with circular polarization, the induced nonlinear index change has a factor 2/3 lower than the clockwise pulse. Thus, from Eq. (3) the condition of maximum transmission corresponds to a loop length of $L=2\pi L_{NLC}$. In the case of solitons $L_D=L_{NLC}$, this condition can be expressed as $L=2\pi L_D$. The evolution of the pulses and the differential nonlinear phase shift in the NOLM is more complicated because only the pulse propagating in the counterclockwise direction is a soliton, however, the numerical calculations show that the optimal length to achieve complete transmission has to be equal to $5.7L_D$ of the corresponding soliton. This feature of the NOLM transmission provides the possibility to adjust the loop length to obtain maximum transmission for a desired soliton. Figure 3 shows the numerically calculated optimum loop length for solitons with T_{FWHM} ranging from 0.1 ps to 1.7 ps.

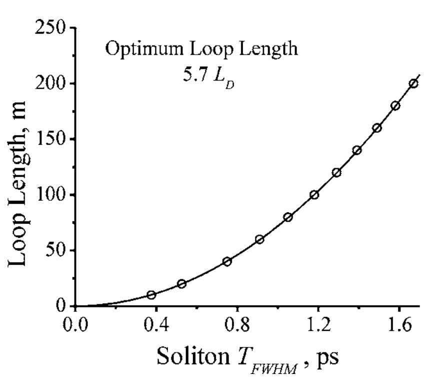

Fig. 3. Optimum loop length to obtain complete transmission for solitons with T_{FWHM} ranging from 0.1 ps to 1.7 ps. Circles show the calculated optimum lengths and the curve shows the approximation $L=5.7L_D$.

4. SOLITON EXTRACTION

As an illustration, we investigated soliton extraction using the configuration shown in Fig. 1. We analyzed the evolution of an input Gaussian pulse with 10 W peak power and T_{FWHM} equal to 20 ps. The pulse propagates through Fiber 1 where the pulse breakup occurs. Figure 4 shows the output waveform at a distance of 1.1 km. The input pulse is also shown in the figure.

The strongest pulse has a sech^2 profile, 45.56 W peak power, and 1.14 ps duration (T_{FWHM}). The soliton number N for this pulse is equal to 1.1. For the smaller pulses the duration ranges from 1.68 to 3 ps, and the soliton numbers are estimated to be close to 1. This output waveform passes through the PC and is amplified by the EDFA. Figure 5 shows the transmitted waveform at the NOLM output considering different amplifications of the EDFA. For this particular case the QWR is adjusted to have zero low-power NOLM transmission, whereas for higher power levels the nonzero NOLM transmission reaches the value of 1 when the nonlinear phase difference reaches π.

The results shown in Fig. 5 can be analyzed using the transmission curves from Fig. 2. The output waveform in Fig. 5(a) shows a case in which the transmission is low for solitons longer than 1 ps. Therefore, only a few percent of the strongest pulses are transmitted. However, the transmission of the 1.1 ps soliton is 3.6 times higher than for the next soliton with 1.68 ps duration, and the contrast between the strongest and the next pulse is 19. The transmitted pulse has the soliton number $N=0.32$ and T_{FWHM} equal to 1.1 ps. In Fig. 5(b) the transmission of the 1.1 ps soliton is still lower than 1; however, its transmission has increased significantly and is about 8 times higher than the transmission of the next solitons. As a result the strongest pulse is transmitted with a contrast of 48. Thus the 3 times amplification allows higher transmission and higher contrast of the 1.1 ps soliton than in the case of Fig. 5(a). The soliton number of the highest pulse at the NOLM output equals 1.14 and the T_{FWHM} is 0.7 ps. In Fig. 5(c) the transmission of the 1.1 ps soliton is nearly equal to 1; however, the transmission of longer solitons also increases, and the contrast is reduced to 19. The highest transmitted pulse has T_{FWHM} of 0.66 ps and soliton number equal to 1.63. For the waveform shown in Fig. 5(d) the transmission of the 1.1 ps soliton is nearly the same as in the case of Fig. 5(c); nevertheless, the transmission of longer solitons increases, resulting in the de-

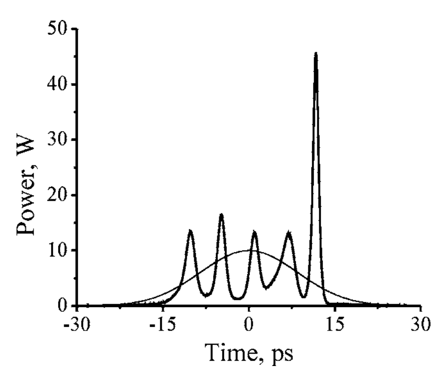

Fig. 4. Input (thin solid) and output (thick solid) waveforms from Fiber 1.

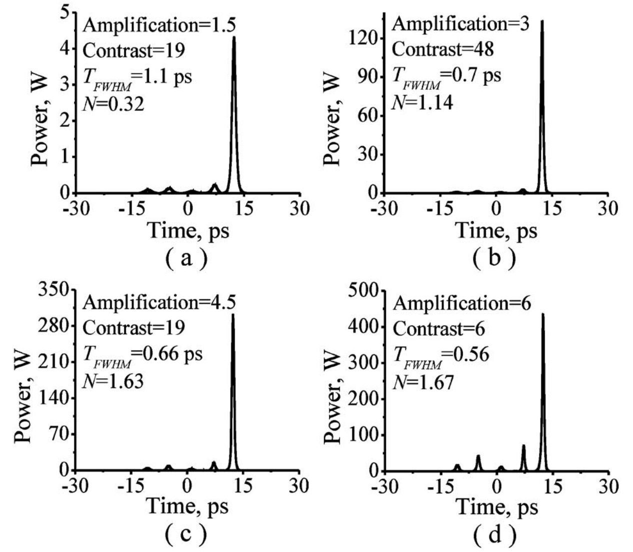

Fig. 5. Transmitted waveforms at the NOLM output considering different amplifications of the EDFA: (a) 1.5, (b) 3, (c) 4.5, and (d) 6.

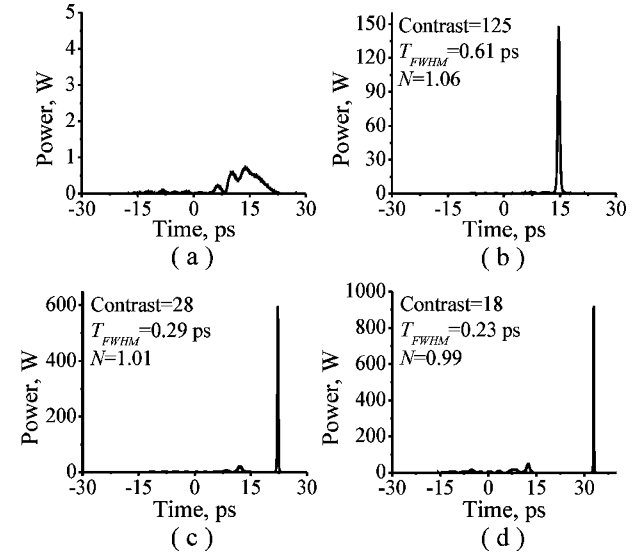

Fig. 6. Output pulses from the 100 m Fiber 2 considering the waveforms at the NOLM output shown in Fig. 5. (a) Strong dispersive effect for low-amplitude pulses. (b–d) Dispersive and nonlinear effects improve the quality of the transmitted pulse, achieving higher contrast and forming a fundamental soliton.

creasing of the contrast. The soliton duration at the fiber output is equal to 0.56 ps with a soliton number of 1.67. The pulse energy of the transmitted pulses in Figs. 5(a)–5(d) is 5.38, 106.15, 225.73, and 277.67 pJ, respectively.

An important feature that we can see from Fig. 5 is that the amplitude of the unwanted pulses is low, and the corresponding soliton number for such pulses is lower than 1. In the presence of anomalous dispersion, both dispersion and nonlinear effects play an important role. For low-intensity pulses ($N<1$), dispersion effects dominate and give rise to pulse broadening. For pulses with higher soliton number ($N>1$) the nonlinearity dominates, and the pulse experiences a narrowing effect defined by the input power. It was also shown that if the pulse does not correspond exactly to an optical soliton for N in the range between 0.5 and 1.5, the pulse adjusts its shape and width as it propagates along the fiber and evolves into a fundamental soliton. [41,42]. Taking advantage of this property, the quality of the transmitted pulses can be improved by employing at the NOLM output an additional fiber used as dispersive nonlinear medium. The purpose of the additional fiber is to disperse the amplitude of unwanted pulses and to form a fundamental soliton. In the calculations the pulses at the NOLM output are launched into a 100 m Fiber 2, whose parameters correspond to the Corning SMF-28 fiber. Figure 6 shows the output pulses from Fiber 2 considering the transmission of the pulses at the NOLM output shown in Fig. 5.

The dispersion effect in the fiber improves the contrast between the highest and the next pulse by reducing considerably the amplitude of unwanted pulses. However, the energy of unwanted pulses keeps constant as a continuous background. This limitation can be effectively overcome by employing an additional NOLM to remove the low-level background component. The contrast achieved for the output pulses in Figs. 6(b)–6(d) corresponds to 125, 28, and 18, respectively. For these cases, the pulse with soliton number higher than 1 undergoes a pulse compression effect followed by a self-frequency shift. The transmitted pulses have a sech^2 profile; soliton numbers of 1.06, 1.01, and 0.99; and T_{FWHM} equal to 0.61, 0.29, and 0.23 ps, respectively. However, the energy of the pulses is reduced to 102.38, 196.52, and 240.24 pJ, respectively. The difference in energy is due to the fact that the soliton number of the pulses before being transmitted through Fiber 2 does not correspond exactly to an optical soliton, and as a result part of the pulse energy is transferred as a dispersive wave that does not form a soliton. The time–bandwidth product for such pulses is 0.38, 0.36, and 0.32, respectively, which is close to the transform-limited value of 0.315 of a hyperbolic-secant pulse.

The above results suggest that by employing this method, the amplification of the EDFA plays an important role to obtain the highest quality pulse at the output. As a consequence, an optimum amplification can be expected to yield the maximum contrast between the desired and unwanted pulses. With the aim of analyzing how amplification influences the process, we calculated the ratio between the energy of the desired and remaining pulses. Figure 7(a) shows the ratio between the energy of the desired and remaining pulses, and Fig. 7(b) shows the power ratio between the peak power of the strongest pulse and the next one.

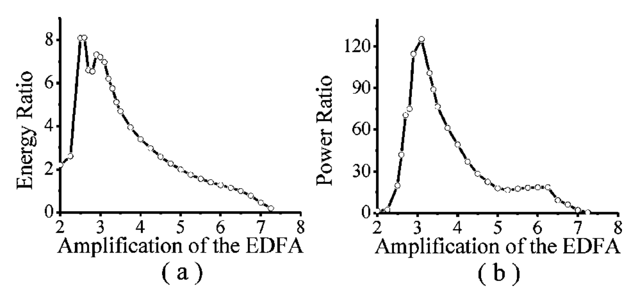

Fig. 7. (a) Energy ratio between the energy of the desired and the remaining pulses. (b) Power ratio between the peak power of the strongest pulse and the next one.

From Fig. 7 it can be seen that the maximum energy ratio is achieved for an amplification of 2.6, whereas the maximum power ratio is achieved with an amplification of 3.1. However, for an amplification of 2.6 the power ratio is decreased by just a few percent. For values of amplification lower than 2.6 the power and energy ratios drop abruptly, because low amplification causes low-intensity pulses that propagate along the NOLM loop, and as consequence dispersion effects strongly degrade the contrast. For amplifications values higher than 3, the energy ratio and the power ratio decrease due to the shift of the NOLM transmission maximum to longer solitons. As a result, unwanted pulses benefit from higher transmission. However, amplification values between 3 and 6 produce reasonably good results. A significant portion of the energy is contained in the desired pulse, and the power ratio could be higher than 18. From these results we can see that the soliton duration can be changed from 0.23 ps to 0.61 ps just by properly adjusting the amplification of the EDFA. Hence, one can set the system such that only the desired soliton will be transmitted. We believe that the suggested method can be very useful for producing solitons with desirable durations to be applied to the study of nonlinear phenomena in optical fibers.

5. CONCLUSIONS

We investigated numerically the transmission of a bunch of solitons resulting from pulse breakup through a NOLM and found that under some conditions a fundamental soliton can be extracted. For the particular case of a 20 ps input Gaussian pulse of 10 W peak power, the results demonstrate that the NOLM exhibits a selective transmission that is strongly dependent on the soliton duration, the NOLM loop length, and the amplification of the solitons before being launched into the NOLM. Therefore, one can set the system such that only one desired soliton will be transmitted. The results show that by properly selecting these parameters it is possible to obtain high contrast at the NOLM output. The contrast obtained in a 37 m NOLM configuration for our particular case was 45. However, the contrast and the pulse quality can be improved by employing an additional fiber used as dispersive nonlinear medium at the NOLM output. The additional fiber disperses the amplitude of unwanted pulses and contributes to form a fundamental soliton. As a result, with the proposed configuration it is possible to improve the contrast up to 125 and to obtain fundamental solitons of sub-ps duration. Besides, an important property of the system is that we can tune the soliton duration at the output in the range between 0.23 ps and 0.61 ps by only changing the amplification of the EDFA. We believe that the suggested method can be useful for producing fundamental solitons with desirable soliton durations.

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