High-repetition-rate ultrashort pulse generation in nonlinear fibers with exponentially decreasing dispersion

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Abstract: A simple method for the generation of ultrashort pulse train with high-repetition-rate is proposed and demonstrated numerically.
OCIS codes: (320.5520) Pulse compression; (320.5540) Pulse shaping

1. Introduction

High-repetition-rate ultrashort optical pulses are widely used in optical time-division-multiplex communications, optical imaging and modern instrumentation [1]. Femtosecond pulse train can be generated in passive mode locked lasers, but the repetition rate is typically smaller than 1 GHz. For active mode locked lasers, it is difficult to generate a pulse train with repetition rate higher than 40 GHz because of the use of modulator inside the cavity. Soliton-like pulse train at high repetition rate by induced modulation instability in optical fibers is demonstrated by Hasegawa in 1984 [2]. Pulse trains at 300 GHz repetition rate have been achieved using this technique [3]. However, individual pulses suffer from significant pedestal generation, leading to nonlinear interactions between neighboring solitons. The adiabatic compression of a dual-frequency signal inside a dispersion decreasing fiber (DDF) has been used to generate a stable train of pedestal-free, non-interacting solitons [4]. But the dispersion inside the DDF must decrease sufficiently slow, thus a relatively long fiber is required. Recently, we have demonstrated the pedestal-free and nearly chirp-free pulse compression of chirped solitary pulses in nonlinear fibers/gratings with exponentially decreasing dispersion using the self-similar analysis [5]. Another advantage of this compression scheme is that the adiabatic condition does not need to be satisfied and rapid compression is possible. In this paper, we propose a high-repetition-rate soliton-train source based on the compression of a dual-frequency optical signal in nonlinear fibers with exponentially decreasing dispersion. The repetition rate is determined by the frequency of initial sinusoidal modulation, and we can easily realize a large beat frequency, even 1 THz, by coupling two continuous waves (CWs) from laser diodes (LDs). We demonstrate numerically the formation of a 160-GHz train of ~200 fs pulses.

2. Numerical Model

Pulse propagation inside the nonlinear fiber is governed by the nonlinear Schrödinger equation

$$i\frac{\partial A}{\partial z}-\frac{\beta_2(z)}{2}\frac{\partial^2 A}{\partial^2 t}+\gamma|A|^2 A=0 \tag{1}$$

where A is the slowly varying envelop, z is the distance variable, t is the time variable, $\beta_2(z)$ and γ are the dispersion and nonlinearity coefficients of the fiber. Here $\beta_2(z)$ varies exponentially as $\beta_2(z)=\beta_{20}\exp(-\sigma z)$, where β_{20} and σ are the initial dispersion and decay rate of the fiber dispersion respectively. The coherent beating between the two CWs generates a sinusoidally modulated optical signal $A_0\sin(\pi t/T_0)$, where A_0 and T_0 are the amplitude and pulse width parameters. Since the linear chirp facilitates efficient pulse compression, we will add a prechirping process for the initial sinusoidally modulated optical signal. We assume the pulse train after the prechirping process is in the form of $A(z=0,\ t)=\sum_{n=-16}^{-1} A_0\sin(\pi t/T_0)\exp\{i\alpha_{20}[t-(n+0.5)T_0]^2/2\}$, $t\in[nT_0,\ (n+1)T_0]$ + $\sum_{n=1}^{16} A_0\sin(\pi t/T_0)\exp\{i\alpha_{20}[t-(n-0.5)T_0]^2/2\}$, $t\in[(n-1)T_0,\ nT_0]$. This prechirped pulse is used as the input of the fiber. According to the self-similar analysis in [5], $\sigma=\alpha_{20}\beta_{20}$.

3. Numerical Results

Figure 1 shows the input and output pulse train in linear (a, c) and logarithmic scales (b, d) where input pulse train and dispersion are described in Section 2. For the input pulse, the initial pulse width parameter $T_0 = 6.25$ ps which corresponds to a repetition rate of 160 GHz and the initial chirp parameter $\alpha_{20} = -0.1$ THz^2. The fiber parameters are $\beta_{20} = -2$ ps^2/km, $\gamma = 2$/W/km, and $L = 10$ km. A particular peak power ($A_0^2 = 8\pi^2|\beta_{20}|/3/T_0^2/\gamma$, which is based on a sinusoidal pulse ansatz) is used here. From Fig. 1, the initial pulse undergoes effective compression (the FWHM decreases from 3.125 ps to 0.225 ps) and the pulse shape has evolved from sinusoidal into hyperbolic secant form.

The time bandwidth product for each pulse in the train decreases from 0.595 to 0.323, which is very close to 0.315, the value for transform-limited hyperbolic secant pulse. From Fig. 1(d), the pedestal energy is almost negligible (3.2%). The amount of pedestal is calculated using the method described in [6]. Figures 1(e) and 1(f) show the input dual-frequency signal spectrum and output spectrum of the soliton train respectively. The compressed pulse experiences obvious bandwidth broadening, as shown by the solid and dashed curves in Fig. 1(g) which represent the input and output spectrum of a single pulse in the pulse train. We also note that the ratio between the soliton separation and soliton pulse width is as large as 27.8 in this example.

Figure 1(h) considers the compression factor and pedestal if different initial peak power A_0^2 / ($|\beta_{20}|/T_0^2/\gamma$) = 3.526^2, 15, 20, $8\pi^2/3$, 30, 35 is used. The number 3.526^2 corresponds to a hyperbolic secant ansatz. All the other parameters are the same as those used Fig. 1(a-g). For different initial peak power, the corresponding nonlinear length L_N = 1.57 km, 1.3 km, 0.98 km, 0.74 km, 0.65 km, 0.56 km. Dots and circles represent the compression factor and pedestal energy (%), respectively. Generally, a higher initial peak power gives a higher compression factor without significant degradation in the pedestal. In all the examples in Fig. 1(h), the compression factor varies from 5 to 20, while the amount of pedestal is always smaller than 5%.

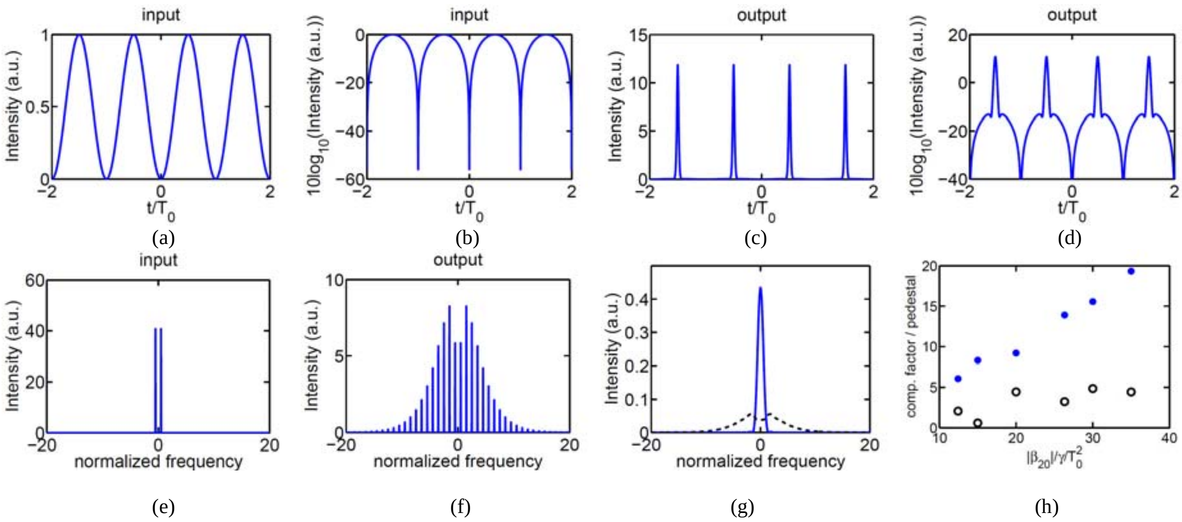

Fig. 1. Input and output pulse train in linear (a, c) and logarithmic scale (b, d) where input pulse train and dispersion are described in Section 2; (e) Input dual-frequency signal spectrum and (f) and output spectrum of the soliton train; (g): spectrum of a single pulse in the input pulse train (solid curve) and spectrum of a single pulse in the output pulse train (dashed curve); (h) compression factor (dots) and pedestal energy (circles) versus different input peak power.

4. Conclusion

In this paper we have proposed a high-repetition rate soliton-train source based on a nonlinear fiber with the exponentially decreasing dispersion. We numerically demonstrate the possibility of a 160 GHz train of ~200 fs pulses by reshaping a dual-frequency signal into a train of solitary pulses.

5. References

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