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Optics & Laser Technology 36 (2004) 613–616
Optics & Laser Technology
www.elsevier.com/locate/optlastec

A simple method for clock recovery

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Received 11 June 2003; received in revised form 24 December 2003; accepted 5 January 2004

Abstract

All optical bit clock recovery is one of the key technologies for all optical 3R recovery. In this paper, a simple method applying the combination of Fabry–Perot (F–P) filter and semiconductor optical amplifier (SOA) for clock recovery is proposed. The effect of the F–P filter finesse on the clock recovery and the reduction in the amplitude fluctuation of the clock pulse by the SOA are discussed theoretically. With this technology 10 Gbit/s clock recovery with equal amplitude and wavelength transparency was realized experimentally.

Keywords: Clock recovery; F–P filter; 3R regeneration

1. Introduction

In high-speed optical fiber networks, the cumulative noise of EDFA, the non-linearity of the fiber, the group velocity dispersion (GVD), the polarization mode dispersion (PMD) and cross-talk etc., will seriously affect the quality of optical communication. 3R regeneration (Re-timing, Re-shaping, Re-amplification) in the transmission system is an effective method to overcome these problems [1].

In the 3R regenerator, the recovered bit clock pulses with low jitter, high signal noise ratio (SNR) and good wave form from the data stream pass an optical switch as the probe signal, which is controlled by the data pulses, then the regenerated data signal with high quality can be obtained. Therefore the clock recovery is a key technology in the 3R regeneration.

The present technologies for the clock recovery can be divided into three kinds. The first technology is with the injection locking of the multi-section self-pulsation laser diode for clock recovery [2]. However, the self-pulsation laser is not readily available commercially because of the complex manufacturing technology. The second kind of technology is utilizing the injection mode locked laser based on fiber or semiconductor components [3–5]. The clock pulses recovered by this technology have good waveforms, but the cavity length of the laser must strictly match the bit rate of the injection signals. The lasers based on semiconductor components still have pattern effects and bit rate restriction. Furthermore, clock recovery with this technology is not wavelength transparent. The third kind of the technology for clock recovery is direct filtering out the frequency components of the clock signal with Fabry–Perot(F–P) filter [6,7]. This is very simple and very fast. The clock can be recovered within few bits, and the wavelength is transparent with respect to the data signal. However, the finesse of the F–P filter must be very high, otherwise there will be amplitude fluctuation in the clock pulses. In [7], an ultra-fast nonlinear interferometer (UNI) was used to reduce the amplitude fluctuation. But the UNI is very complex and expensive, which increases the cost of the clock recovery.

In this paper, the combination of the F–P filter and the semiconductor optical amplifier (SOA) is proposed for clock recovery. This method not only has the advantage of the third kind of the technology in the above, but also uses the fast gain saturation of the SOA to depress the amplitude fluctuation. The cost of the SOA is greatly reduced because of the more efficient manufacturing technology. Therefore, this method is simple and is low cost. In this paper we discuss, theoretically, the effect of the F–P filter finesse on the clock recovery and the reduction in the amplitude fluctuation by the SOA . With this technology, 10 Gbit/s clock recovery with consistently equal amplitude and wavelength transparent was realized experimentally.

2. Principle of the technology

The schematic diagram of the technology is shown in Fig. 1. The return-to-zero (RZ) optical data signal passes

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doi:10.1016/j.optlastec.2004.01.007

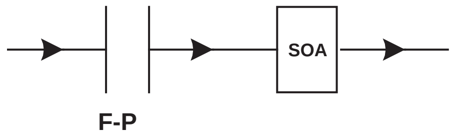

Fig. 1. Schematic diagram of the technology.

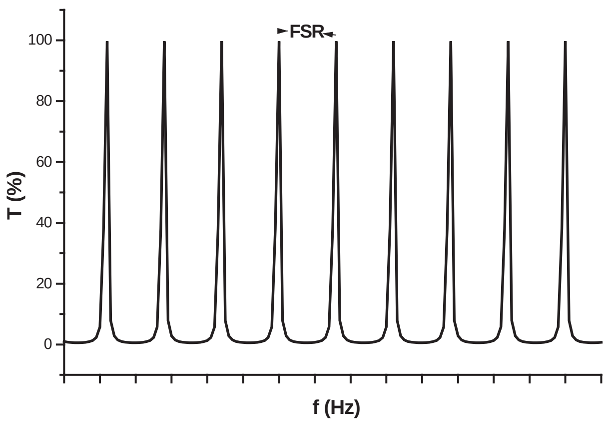

Fig. 2. Transmission curve of the F–P (FSR: free spectrum range).

through the F–P filter first, where the free spectrum range (FSR) is equal to the bit rate of the data signal. Then the signal passes through a SOA that is operated to gain saturation state. Finally clock pulses with amplitude equalization and wavelength transparent to the data signal are recovered.

The principle of the clock recovery by the F–P filter can be analyzed from the frequency domain and time domain, respectively. The transmission of the F–P filter can be written as

$$T = \frac{1}{1 + F\sin^2(\delta/2)},$$

where

$$F = \frac{4R}{(1-R)^2}, \quad \delta = \frac{4\pi h}{\lambda},$$

R is the reflectivity of the mirrors of the F–P filter at wavelength λ, h is the distance between the mirrors.

Fig. 2 shows the transmission curve with the optical frequency f. The free spectrum range (FSR) and finesse of the F–P is

$$\mathrm{FSR} = \frac{c}{2nh}, \quad \mathrm{FIN} = \frac{\pi\sqrt{R}}{1-R},$$

where c is the velocity of the light in vacuum. If the medium between the two mirrors is air, the refractive index n is approximately 1.

The optical spectrum of signal with date rate of B (bit/s), shown in Fig. 3, contains not only the components spaced by B (Hz) but also other continuous frequency components related with the data pattern. When the data signals pass the F–P filter with the FSR of B, the clock frequency components spaced by B (Hz) will pass the

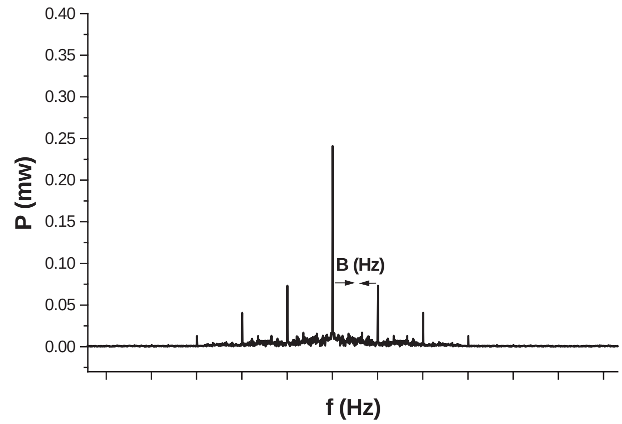

Fig. 3. Optical spectrum of the B bit/s data signal.

F–P and most of the other components are filtered off [8] then in time domain the data signal turns to clock pulses. Because of the low finesse of the filter, some frequency components related with the data pattern will pass the F–P and become data pattern noise affecting the clock pulses. In the time domain this results in amplitude fluctuation.

The problem can also be analyzed in the time domain. When the B (bit/s) data-modulated pulses pass the F–P filter, which has the FSR of B (Hz), the pulses of the ‘1’ slot will be reflected backward and forward in the F–P cavity, so optical pulses will be inserted in the ‘0’ slots. Thus after passing through the F–P filter, all ‘0’ data becomes ‘1’ ones. If the reflectivity of the mirrors is not very high, the optical pulses are gradually attenuated when they are reflected backward and forward in the cavity. This results in amplitude fluctuation in the recovered clock pulses.

To overcome the amplitude fluctuation, a SOA was inserted after the F–P filter. When the optical clock pulses with amplitude fluctuation pass through the SOA, the pulses with lower peak power will be more highly amplified. On the other hand, the pulses with more peak power will get less gain. So the gain saturation of SOA can reduce the amplitude fluctuation of the optical pulses.

The dynamic gain of the SOA can be described in the following equations [9]:

$$P_{\mathrm{out}}(t) = P_{\mathrm{in}}(t)\exp[h(t)-\alpha], \phi_{\mathrm{out}}(t) = \phi_{\mathrm{in}}(t) - \beta h(t)/2,$$

$$h(t) = \int_0^L g(z,t)\,\mathrm{d}z,$$

$$\frac{\mathrm{d}h}{\mathrm{d}t} = \frac{1}{1+\chi\exp(h)P_{\mathrm{in}}} \times \left\{\frac{h_0 - h}{t_{\mathrm{c}}} - \chi[\exp(h)-1]\frac{\mathrm{d}P_{\mathrm{in}}}{\mathrm{d}t} - [\exp(h)-1]P_{\mathrm{in}}\left(\frac{\chi}{t_{\mathrm{c}}} + \frac{1}{P_{\mathrm{sat}}t_{\mathrm{c}}}\right)\right\},$$

where $g(z,t)$ is the gain coefficient, L is the length of SOA; $h_0 = g_0 L$, g_0 is the small signal gain coefficient; χ is sum of the nonlinear gain factors associated with the linewidth enhancement. P_{in} is the optical power injected to the SOA at

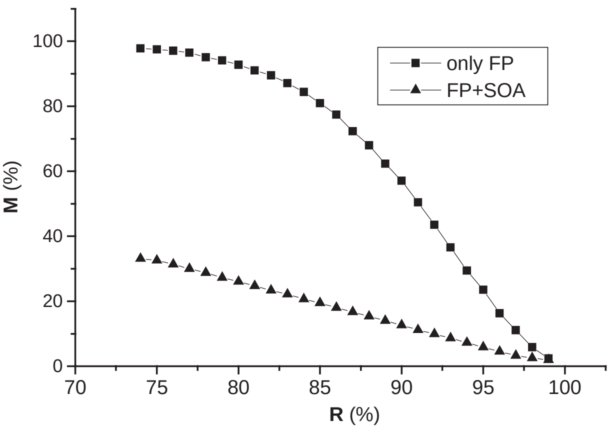

Fig. 4. The relation curve between the M and R.

time t. P_{out} is the optical power after being amplified by the SOA. t_c is the carrier lifetime, P_{sat} is the saturation power of SOA. ϕ_{in} and ϕ_{out} are the phase of the light being injected into and passing out of the SOA, respectively. α is the total loss of SOA and β is the linewidth enhancement factor.

A parameter $M = (P_p^{max} - P_p^{min})/(P_p^{max} + P_p^{min}) \times 100\%$ is defined to show the amplitude fluctuation of the optical pulses. P_p^{max} and P_p^{min} are, respectively, the maximum and minimum peak power of the clock pulses. $M = 0$ implies there is no fluctuation in the clock pulse train. We numerically simulated the clock recovery with F–P only and with combination of F–P and SOA. In the simulation, the data signal we used was a pulse train that contained $(2^7 - 1)$ bits with wavelength of 1554 nm. There were 7 consecutive '0' and 7 consecutive '1' in the data stream.

With the above mathematic model, the relation between the amplitude fluctuation of clock pulses and the reflectivity R is shown in Fig. 4. The parameter M decreases with increasing R. The gain saturation of the SOA can greatly reduce the amplitude fluctuation.

3. The experimental results

In the experiment, the data signal was RZ pseudorandom data $(2^{31} - 1)$ with a bit rate of 10 Gbit/s, which was obtained by optical-time-multiplexing (2.488 Gbit/s $\times$ 4) at the wavelength of 1554 nm. The eye diagram is shown in Fig. 5. The data signal passed through a F–P filter and a SOA for clock recovery. The F–P filter we used was composed of two parallel mirrors with reflectivity of about 80%, giving an F–P finesse of about 14. The FSR of the F–P filter was adjusted to 10 GHz.

Fig. 6 shows the clock waveform of signal after F–P only. Because of the low finesse of F–P filter, there was large amplitude fluctuation in the waveform.

In the experiment, the operated current of SOA was 150 mA and the saturation output power was 2.5 mw(4 dBm). Fig. 7 shows the clock waveform of the signal after passing the F–P filter and SOA. Compared to

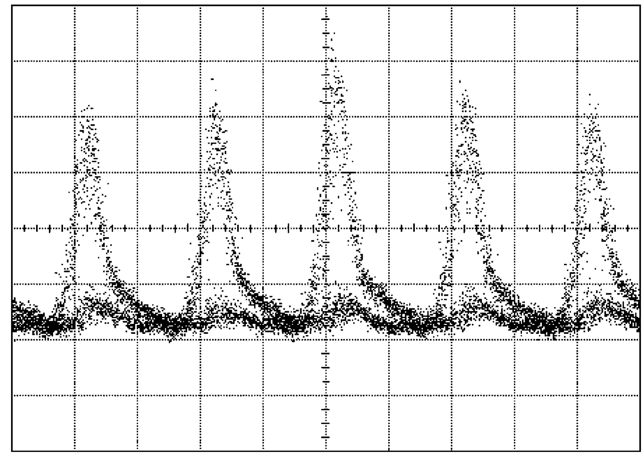

Fig. 5. Eye diagram of 10 Gbit/s data signals (Y:8.7 mV/div; X:50 ps/div).

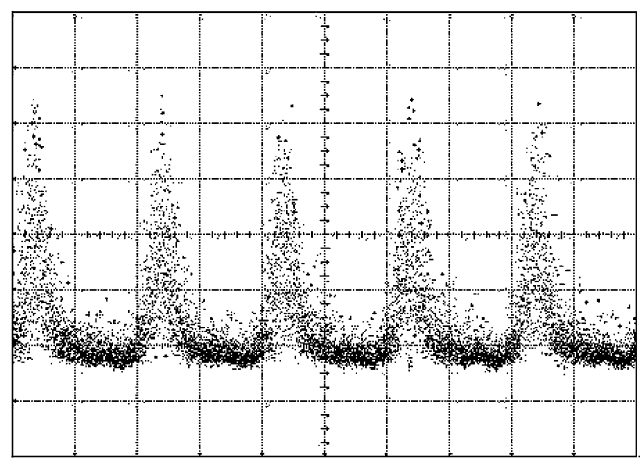

Fig. 6. Waveform of clock signals after F–P (Y:32.6 mV/div; X:50 ps/div).

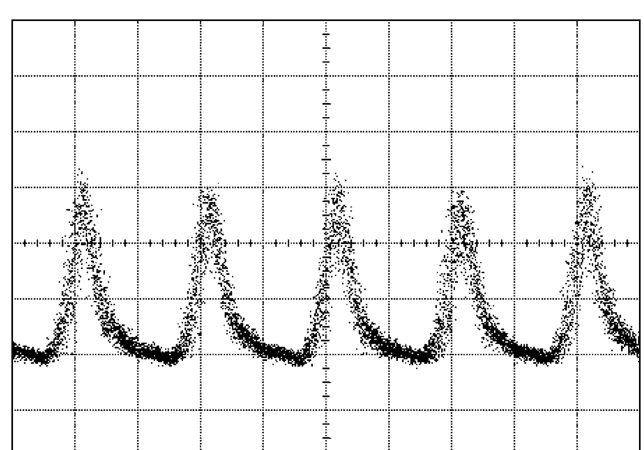

Fig. 7. Waveform of clock signals after F–P and SOA (Y:32.6 mv/div; X:50 ps/div).

Fig. 6, the amplitude fluctuation was greatly reduced by the gain saturation of SOA.

In our experiment, because of the low finesse of the F–P filter, there was still some amplitude fluctuation after passing the SOA. To reduce the amplitude fluctuation ulteriorly, a F–P filter with higher finesse is suggested.

4. Conclusion

Direct clock recovery with F–P filter is a relatively simple and wavelength transparent method. However, because of the low finesse of F–P filter, there is large amplitude fluctuation in the clock pulses. Numerical simulation shows that the amplitude fluctuation decreases with increasing F–P filter finesse. The amplitude fluctuation can be greatly reduced via the gain saturation of an SOA. With the combination of an F–P filter and an SOA, 10 Gbit/s clock recovery with consistently equal amplitude and wavelength transparency was realized experimentally.

Acknowledgements

This work was supported by 863 Project of China and the National Natural Science Foundation of China. No. (60072017,60177019).

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