Novel approach to reduce the pattern effect in 10-Gb/s clock recovery

Tong Wang (王 桐), Caiyun Lou (娄采云), Li Huo (霍 力), and Yizhi Gao (高以智)

Department of Electronic Engineering, Tsinghua University, Beijing 100084

Received September 4, 2003

A Fabry-Perot (F-P) etalon and a semiconductor optical amplifier (SOA) were combined to preprocess the data signals before clock recovery. With this technology in the 10-Gb/s clock recovery utilizing injection mode-locked laser (IMLL) based on SOA, the amplitude fluctuation and timing jitters caused by the pattern effect in recovered clock pulses were greatly reduced, experimentally. It also demonstrated that clock could be recovered from the very degraded signals.

OCIS codes: 060.4510, 320.7130, 140.3520, 250.5980.

Clock recovery is one of the key technologies in the 3R (re-timing, re-shaping, and re-amplifying) regeneration system. Different technologies of clock recovery have been reported[1−4]. Injection mode-locked laser (IMLL) based on semiconductor optical amplifier (SOA) is a simple method for all-optical clock recovery[3,4]. However, there are serious pattern effects in clock pulses recovered with this technology[5]. In Ref. [5], we have proposed a technology named comb-like filter preprocessing to reduce the pattern effect, which was demonstrated by numerical simulation.

In this paper, with a comb-like filter and a SOA combined together for preprocessing the data signal, pattern effect was greatly reduced in the experiment for optical 10-Gb/s clock recovery using IMLL based on SOA. It was also proved that clock pulses could be recovered from very degraded data signals.

The Schematic diagram of IMLL clock extractor is shown in Fig. 1. Detail principle of the IMLL was analyzed in Ref [4].

In our experiment, the SOA in the loop was operated with a DC bias current of 200 mA. The small signal gain of the SOA was 20 dB and saturation power was 4 mW. The length of the loop was about 11.3 m. The total loss of the other components was 4 dB. The injected data signal was return-to-zero (RZ) pseudorandom data ($2^{31}-1$) with a bit rate of 10 Gb/s, which was obtained by optical-time-multiplexing (2.488 Gb/s × 4) at the wavelength of 1554.5 nm. The central wavelength of the optical band pass filter (OBPF) in the cavity was at 1535 nm. The pulse trace and the eye diagram were displayed by a sampling scope (Agilent 86100A) with a module (83484A).

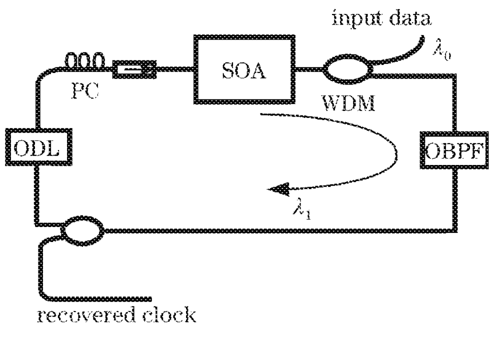

Fig. 1. Schematic diagram of IMLL clock extractor based on SOA (OBPF: optical band pass filter; ODL: optical delay line).

The sampling scope had a function of analyzing the mean amplitude (MA) and standard deviation (STD) of the amplitude of the pulse trace. A parameter called as relative standard deviation (RSTD) was defined to figure the amplitude fluctuation, where RSTD = STD/MA.

In our experiment, a RF spectrum analyzer was used to show the RF spectrum of the clock pulses. An expression[6] $\sigma_c = \frac{1}{2\pi n f}\sqrt{\frac{p_n}{p_c}\frac{\Delta f}{\mathrm{RB}}}$ was applied to evaluate the root-mean-square (rms) timing jitter of the clock pulses, where σ_c was the rms timing jitter, n was the harmonic number (here $n = 1$), RB was the resolution bandwidth of the RF spectrum analyzer, p_c and p_n were the powers of the nth harmonics and the maximum of the phase noise centered on the harmonics, respectively, and Δf was the noise bandwidth (full width at half maximum (FWHM)).

In the experiment, the average power of the injected data signal was about 1.5 mW. Figures 2(a), (b) and (c) are the waveform, RF spectrum and optical spectrum of the recovered 10-GHz clock pulses, respectively, and the parameters in the figure are shown in Table 1.

From Table 1, the RSTD of amplitude and the rms timing jitter were 14.3% and 1.68 ps, respectively. The large amplitude fluctuation and timing jitter in the waveform were ascribed to the pattern effect. The optical spectrum without clearly split spectrum line indicated that mode-locking was not achieved ideally.

To overcome the pattern effect, the data signal was preprocessed before being injected into the IMLL. The schematic diagram of clock recovery with preprocessing technology is shown in Fig. 3. In our experiment, the comb-like filter was a Fabry-Perot (F-P) etalon, which was composed of two mirrors with reflectivity about 75% (with fineness about 11). The free spectrum range (FSR) was 10 GHz (0.08 nm). The 10-Gb/s data signal passed the F-P etalon and a SOA and then was injected into the IMLL. The FSR of the F-P etalon was nearly equal to the line rate of the data. After passing the F-P etalon, optical pulses were inserted in the '0' slots of the data signal[5]. Then the data signal became to pulse stream with unequal amplitude. The SOA was operated at the saturation amplification region for the pulse with high amplitude. Therefore, only the optical pulses with low amplitude were obviously amplified by the SOA. The experiment results are shown in Fig. 3. After passing the F-P etalon and the SOA, the inequality of the pulse amplitude was more suppressed. Therefore, the number of "0" in the data signal was greatly reduced by the preprocessing technology. The data signal after preprocessing was then injected into the IMLL for clock recovery.

The average power of the signal before the SOA was about 4 mW. The SOA was operated with a DC bias current of 150 mA. The small signal gain of the SOA was 15 dB and saturation power was 3 mW. The injected power before the IMLL was adjusted to 1.5 mW by an optical attenuation.

The clock pulses recovered from the IMLL passed a 30-ps/nm dispersion compensation fiber (DCF) for linear compression. Figures 4(a), (b), (c) and (d) show the waveform, autocorrelation trace, RF spectrum and optical spectrum, respectively. Table 2 contains the parameters obtained by Fig. 4, in which the RSTD was 3.82% and the rms timing jitter was 0.71 ps. Compared to Fig. 2, the amplitude fluctuation and timing jitter were greatly suppressed. The optical spectrum with clearly split spectrum line demonstrated that mode-locking was achieved obviously. The pulse width of the clock was about 10 ps measured by an autocorrelation analyzer.

In the 3R system, clock recovery from the degraded signals was a key technology. Figure 5 shows the eye

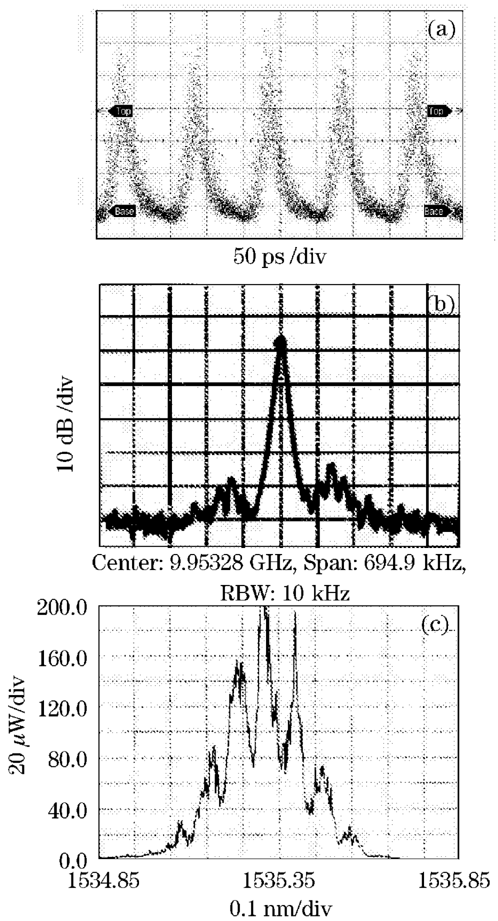

Fig. 2. Waveform (a), RF spectrum (b) and optical spectrum (c) of the recovered clock pulses.

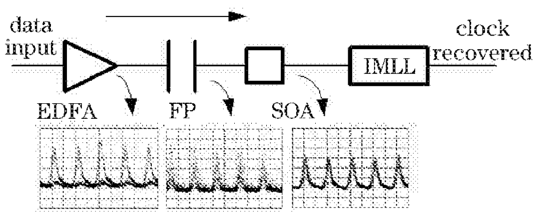

Fig. 3. Schematic diagram of clock recovery with the preprocessing technology.

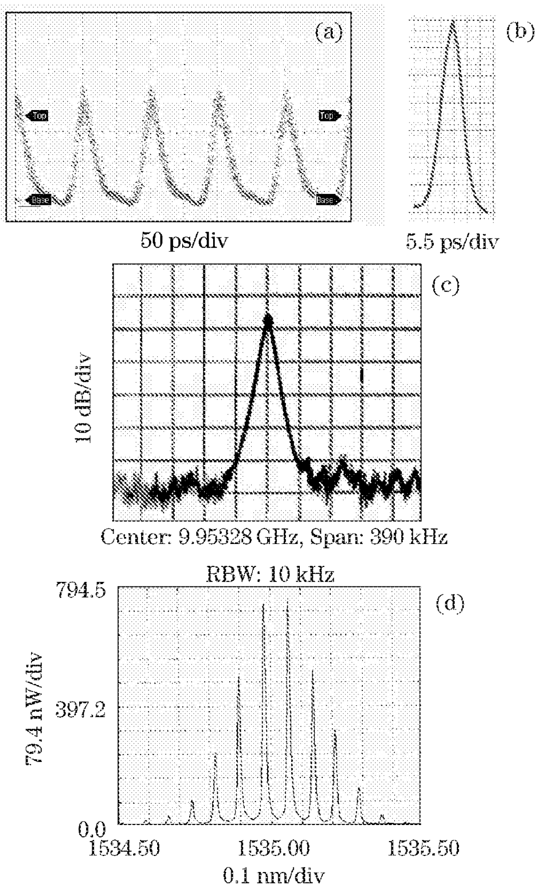

Fig. 4. Waveform (a), autocorrelation trace (b), RF spectrum (c) and optical spectrum (d) of the clock pulses with preprocessing.

Table 1. Parameters Measured in Fig. 2

STD (mV)	MA (mV)	RSTD (%)	f (GHz)
14.37	100.41	14.3	9.95328
p_c/p_n (dB)	Δf (kHz)	RB (kHz)	σ_c (ps)
34	278	10	1.68

Table 2. Parameters Measured in Fig. 4

STD (mV)	MA (mV)	RSTD (%)	f (GHz)
1.59	41.65	3.82	9.95328
p_c/p_n (dB)	Δf (kHz)	RB (kHz)	σ_c (ps)
40	195	10	0.71

diagram of 10-Gb/s degraded data signal, which was obtained by a programmable polarization mode dispersion (PMD) emulator[7], which was composed of a polarization controller (PC) and a crystal based differential group delay (DGD). The degraded signal after preprocessing by the F-P etalon and SOA was injected into the IMLL for clock recovery. The waveform of the clock recovered from IMLL is shown in Fig. 6.

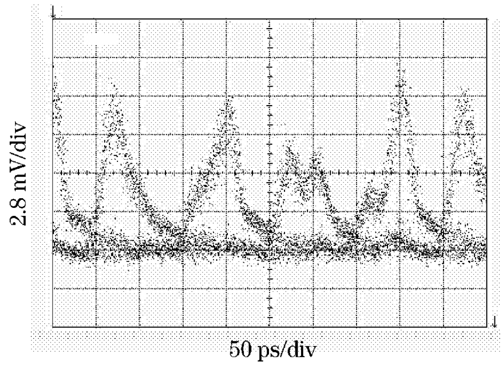

Fig. 5. Eye diagram of degraded 10-Gb/s data signal.

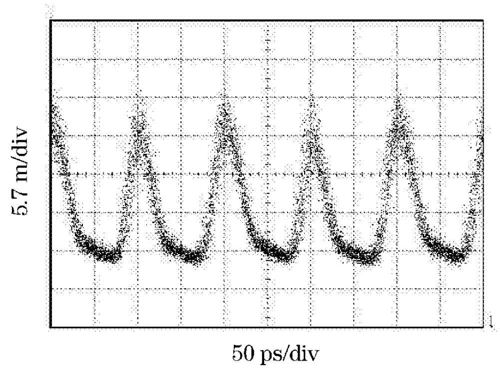

Fig. 6. Waveform of clock pulses recovered from degraded signals.

The RSTD of amplitude and rms timing jitter of the clock pulses were about 4% and 0.8 ps, respectively.

In conclusion, a F-P etalon and a SOA were used to preprocess the data signals before clock recovery. In the 10-Gb/s clock recovery, the relative standard deviation (RSTD) of amplitude and rms timing jitter of clock pulses were reduced to 3.82% and 0.71 ps from 14.3% and 1.68 ps, respectively. Furthermore, clock pulses with a RSTD of 4% and rms timing jitter of 0.8 ps could be recovered from the very degraded 10-Gb/s signal. It is believed that this technology could be applied in the higher speed clock recovery systems.

The authors acknowledge the support of 863 Project of China and the National Natural Science Foundation of China (No. 60072017 and 60177019). T. Wang's e-mail address is wangtong99@mails.tsinghua.edu.cn.

References

1. C. Johnson, K. Demarest, C. Allen, R. Hui, K. V. Peddanarappagari, and B. Zhu, IEEE Photon. Techonol. Lett. **11,** 895 (1999).
2. C. Bornholdt, B. Sartorius, S. Schelhase, M. Mohrle, and S. Bauer, Electron. Lett. **36,** 327 (2000).
3. K. Vlachos, K. Zoiros, T. Houbavlis, and H. Avramopoulos, IEEE Photon. Techonol. Lett. **12,** 25 (2000).
4. D. M. Patrick and R. J. Manning, Electron. Lett. **30,** 151 (1994).
5. T. Wang, Z. H. Li, C. Y. Lou, Y. Wu, and Y. Z. Gao, IEEE Photon. Techonol. Lett. **14,** 855 (2002).
6. P. J. Delfyett, D. H. Hartman, and S. Z. Ahmad, J. Lightwave Technol. **9,** 1646 (1991).
7. H. J. Yao, C. Y. Lou, L. Zeng, X. M. Song, E. Y. Zhang, and Y. Z. Gao, Acta Photon. Sin. (in Chinese) (to be published).