Bit>Error>Rate Performance Enhancement of All-Optical Clock Recovery at 42.66 Gb/s Using Passive Prefiltering

M. N. Ngo, V. Roncin, Q. T. Le, L. Bramerie, D. Chevallier, L. Lablonde, A. Shen, G.-H. Duan, and J.-C. Simon

Abstract—In this letter, we demonstrate the bit-error-rate (BER) performance enhancement of an all-optical clock recovery device at 42.66 Gb/s using a prefiltering operation in front of a self-pulsating semiconductor laser. The prefilter is composed of a simple passive fiber-Bragg-grating-based Fabry–Pérot bandpass filter. The assessment is obtained thanks to BER measurement using a data remodulation technique.

Index Terms—Bragg gratings, clock synchronization, error analysis, optical communication, optical filter, semiconductor lasers.

I. INTRODUCTION

Optical clock recovery (OCR) is a key function of all-optical signal processing for high bit rate above 40 Gb/s [1]. This all-optical approach can be attractive for simple optical 3R regeneration in future high-speed transmission systems [2], [3], or for OCR through a subharmonic locking process [4]. Two main approaches are usually studied for all-optical clock recovery. The first one is a passive technique based on the spectral modulation components filtering thanks to an optical Fabry–Pérot (FP) filter. Its free-spectral range (FSR) corresponds to the data frequency modulation in return-to-zero (RZ) data format [5]. The performance of this simple technique depends intrinsically on optical noise magnitude and input polarization state [6]. The second technique is based on active modulation synchronization in self-pulsating lasers which generates an optical clock signal at the frequency corresponding to data modulation [7], [8]. However, this technique requires a mode-locked laser with ultralow phase noise. Classical bulk based self-pulsating lasers do not have sufficient phase noise performances. On the contrary, recent results demonstrated very high performances of OCR with quantum-dot self-pulsating lasers [9]. In order to improve the quality of OCR, we present in this letter an original solution for OCR quality enhancement. The OCR block is composed by a Bragg-gratings-based FP (FP-BG) filter [10] as a prefiltering function, followed by a self-pulsating distributed Bragg reflector (SP-DBR) laser based on bulk structure. This original setup has been tested in a transmission system at 42.66 Gb/s. The recovered clock quality is assessed via remodulation and the bit-error-rate (BER) measurement method. This technique of optical clock quality assessment in a system environment has already been proposed in [4] and [6].

II. EXPERIMENTAL SETUP

The experimental setup is presented in Fig. 1. The optical data signal is a 33% RZ format with an extinction ratio up to 15 dB and a very low amplitude noise. It is emitted by the transmitter (Tx) which is composed by a distributed feedback (DFB) laser at 1553 nm, a first electrooptic modulator (EOM) driven in at 1553 nm, a first electrooptic modulator (EOM) driven in 2 Vp to generate the 8-ps pulsewidth optical clock at 42.66 GHz, and a second EOM driven by a 42.66-Gb/s pseudorandom binary sequence (PRBS) electrical data of 2^31 – 1 bits. The OCR setup is composed by two parts: the optical bandpass filter (FP-BG) for prefiltering and the mode-locked laser (SP-DBR) for OCR. The wavelength is accurately adjusted to the central peak of the FP-BG filter. The polarization controller allows us to minimize the influence of polarization-dependence loss (PDL) of the filter. An optical circulator (OC) allows injecting the prefiltered signal in the laser and recovering the optical clock. A 5-nm bandpass filter centered at 1547 nm is used to select the wavelength of the mode-locked laser signal at the output. The recovered clock is then optically remodulated by the modulator (M) and analyzed by the receiver through BER measurements.

The SP-DBR laser (from Alcatel Thales III-V Lab) consists of three different sections: Bragg section, phase section, and active section. The electrical modulation linewidth has been measured at 3 dB with a typical value of 1 MHz. The drive current of the gain section is 141 mA for generating an optical self-pulsation at 42.66 GHz. The drive current of the Bragg section is

Fig. 1. Experimental setup.
Fig. 2. Characterization of the prefilter: (a) the FP-BG transmission response; (b) the prefiltered optical clock spectrum and corresponding oscilloscope trace in inset.

33 mA corresponding to an output clock at 1547 nm. In this experimental configuration, the locking range of the laser is close to 40 MHz. A 6- to 10-dBm range of input power is required to lock the laser with optical data. The FP-BG filter (from IX-Fiber) is placed before the SP-DBR laser to prefilter the optical data. The FP-BG is an all-fiber-based device, which is formed by two identical and uniform 1.3-mm fiber Bragg gratings separated by approximately 2 mm. We show in Fig. 2(a) the transmission response of the FP-BG obtained by injecting optical white noise in the filter. We used a high precision optical spectrum with 0.08 pm of resolution for the characterization. Because of the photoinduced birefringence, the FP peaks are duplicated into two classes of FSR of the cavity. In order to reduce influences of this problem, the gratings were photo-written in a polarization-maintaining fiber, which enables us to select separately one of the two FP peak classes by adjusting the input polarization with a polarization controller. The three main peaks are separated by 347 and 342 pm corresponding to FSR of 43.4 and 42.7 GHz. The measured 3-dB bandwidth is 0.7 pm for the central peak and close to 1.5 pm for the adjacent peaks, thus corresponding to a finesse of 500 for the central peak. In this range bandwidth, the filter is not sensitive to the input laser frequency jitter which is typically less than 10 MHz (0.08 pm) for semiconductors DFB lasers. Nevertheless, the bandwidth is about ten times narrower than the wavelength tolerance recommended in wavelength-division-multiplexing specifications. An

Fig. 3. OCR performance using BER measurement of remodulated optical clock from both configurations: without prefiltering (laser) and with prefiltering (prefiltered laser).

insertion loss of 7 dB has been measured for the central peak. This component is packaged in a passive thermal insensitive module without temperature control.

III. EXPERIMENTAL RESULTS

First, we study the prefiltering stage by injecting the optical data at 42.66 Gb/s in the FP-BG filter. We can observe in Fig. 2(b) the optical spectrum showing components of the modulation at 42.66 GHz obtained by 10 pm of a resolution optical spectrum analyzer. However, we mention that the slight shift of transmission peaks wavelength shown in Fig. 2 is caused by the calibration of the two different pieces of equipment. An asymmetric transfer function of the filter introduces an asymmetric prefiltering of the data modulation lines. Therefore, the two adjacent peaks do not have the same power level. In the inset of Fig. 2(b), we observe the corresponding optical clock trace with a 50-GHz bandwidth electrical sampling oscilloscope. This clock is degraded by amplitude noise degradation and has a contrast of only 8 dB. A better quality of the recovered clock would be obtained with a more symmetric filter followed by a semiconductor optical amplifier [6]. In spite of this low clock quality, we used this filter to synchronize the SP-DBR laser.

Now, the all-optical clock recovery performances obtained with and without prefiltering are compared, through BER measurements. The clock remodulation technique is the most efficient way to validate the clock recovery function in a data transmission system environment. The curves obtained for the different configurations are shown in Fig. 3. The sensitivity reference curve of the receiver corresponding to the back-to-back configuration is first plotted (triangles). The configuration corresponding to the SP-DBR laser alone is then plotted (squares), and shows a penalty of 5 dB at a BER of $10^{-8}$ and an error floor around $10^{-9}$. This result is clearly caused by an insufficient quality of the recovered clock, which is probably due to an excessive internal phase noise and an insufficient jitter transfer function of the mode-locked laser.

The last curve (circles) is plotted in the configuration corresponding to the cascade of FP-BG prefilter and the SP-DBR laser. The prefiltering process improves the quality of the output recovered clock. At a BER of $10^{-8}$, the penalty is reduced to 2.5 dB and the error floor disappears. The substantial penalty is
from the laser is 2 ps. Nevertheless, transmission is error-free mainly brought by the response of the receiver with the two different pulsewidths: the reference is 8 ps and the clock extracted from the laser is 2 ps. Nevertheless, transmission is error-free for an optical power above ~32 dBm at the receiver input. The enhancement of the clock recovery process can be more simply understood by observing temporal traces of the recovered optical clock. Two traces are shown in Fig. 4. They are obtained using an optical sampling oscilloscope with the persistent “eye diagram” mode and a high timing resolution of 1 ps (Picosolve, PSO 100 Series). Fig. 4(a) presents the optical recovered clock at 42.66 GHz from the laser synchronized with optical data at 42.66 Gb/s. Fig. 4(b) presents the optical recovered clock from the laser synchronized with optical clock at 42.66 GHz. Both traces obtained in the similar experimental conditions, allow a qualitative estimation of the clock amplitude noise. Particularly, we observe that the variance on the clock is greater if the laser is synchronized with data. Moreover, we present in Fig. 4(c) the phase noise measurement of the recovered clock injected with optical data or with an optical clock. We show that the noise level of the recovered clock is lower if injected by a clock rather than data. In order to offer a quantitative measurement, we compared these results with the ITU-T G825.1 recommendation on jitter tolerance in clock recovery. We made the measurement in the frequency range [16–320 MHz]. For the clock recovered from data, we measured a jitter root-mean-square (rms) of 629 fs which is above the maximum tolerated of 232 fs. However, the jitter rms for the clock recovered from the laser injected with an optical clock is 125 fs, which is under the threshold and demonstrates a suitable clock quality. We note that the jitter rms value of the injected clock (reference) was 33 fs. Thanks to this comparative analysis, we show that the prefiltering stage leads to a reduction of the amplitude and phase noise introduced by the data modulation in the laser. This stage is useful if the spectral purity of the laser is not sufficient to recover the clock. Thus, in our experiment, the remodulated clock quality is enhanced and we then understand why the error floor observed in Fig. 3 has disappeared.

IV. CONCLUSION

In this letter, we studied the performance enhancement of an OCR based on an SP-DBR laser at 42.66 Gb/s by using a simple passive FP optical prefilter. The proposed prefilter is a fiber-Bragg-gratings-based FP filter with a high finesse, which generates a medium-quality optical clock. This filter is placed before the DBR laser. We showed, thanks to BER measurements, that the penalty is reduced of 2.5 dB and the error floor observed by using the laser alone is removed. Phase noise measurements are also proposed to quantify this effect and to compare the solution to other OCR devices.

ACKNOWLEDGMENT

System results were achieved in the PERSYST Platform.

REFERENCES