40-Gb/s Optical Packet Clock Recovery Using a Travelling-wave Electroabsorption Modulator-Based Ring Oscillator

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Abstract A compact traveling-wave electroabsorption modulator-based ring oscillator is utilized to perform clock recovery and simultaneously reshaping for 40-Gb/s optical packets. The clock locks within 300 ns and has less than 0.6 ps timing jitter.

Introduction Optical packet switching is a promising technique to exploit the optical network capacity. One challenging key function is to extract the clock signal from asynchronously arriving packets. Previously, self-pulsating distributed feedback lasers and Febry-Perot filters have been applied for optical clock recovery (OCR) on a packet per packet basis [1, 2]. In our previous work, we demonstrated a novel technique to recover 40-GHz optical clock with 0.5-ps timing jitter and 8-ps pulsewidth in a non-packet environment. It employs a traveling-wave electroabsorption modulator (TW-EAM)-based ring oscillator [3]. A phase shifter was not used in the OCR, and the loop phase was tuned by adjusting TW-EAM’s bias due to nonlinear photocurrent generation. This allows hybrid integration to reduce the loop length to ~18 mm [4].

In this paper, we analyse the characteristics of the OCR in [3] for packet switching. The clock component of input 40Gb/s optical packets is extracted by a chip coplanar Q-filter ribbon-bonded to a TW-EAM shown as Fig.1. A RF amplifier is used in the loop with external RF cables. The TW-EAM simultaneously works as a photodetector by using photocurrent from upper electrical port and a pulsed optical clock generator by applying recovered electrical clock on lower electrical port to modulate CW light at another wavelength. The modulation effect of recovered electrical clock can perform reshaping and retiming due to narrow synchronized TW-EAM’s switch window [5]. Output signals of the OCR can be launched into a subsequent wavelength converter to achieve 3R at $\lambda_2$.

Locking time and jitter measurement

A 10-GHz gain-switched DBR laser was used to generate pulses at 1555 nm ($\lambda_1$) and modulated with PRBS pattern $2^{31}-1$ through a LiNbO$_3$ modulator. Optical packets were generated by an acousto-optical modulator (AOM) and then optically multiplexed to 40 Gb/s. The CW light input for generating the recovered optical clock was 6 dBm at 1551 nm ($\lambda_2$).
Without an optical signal input, the OCR oscillated at the frequency of 38.858 GHz that is determined by the peak frequency of Q-filter and total loop delay, shown as the inset picture in Fig. 2(a). When optical packets and CW light were injected to the OCR, both clock component and free-running mode exist in the loop, shown as the grey line in Fig. 2(a). By adjusting the reverse bias of the TW-EAM to 0.86 V, the OCR oscillation frequency was tuned close to the input data frequency and its phase was also locked, shown as the dark line in Fig. 2(a). Low frequency modulation characteristics of optical packets generate the sidebands. The recovered ~40-GHz electrical and optical clocks are shown as lower waveforms in Fig. 2(b) and (c), respectively. The overlap of synchronized and unsynchronized clock signals, corresponding to payloads and gaps, lead to smeared pictures due to the sampling nature of the scope.

A mixer was used to measure the locking time of the OCR. ~40-GHz RF signal electrically multiplexed from ~10-GHz RF signal from the transmitter input the LO port of the mixer; recovered ~40-GHz electrical clock input RF port of the mixer. The output IF signal from the mixer is shown as the lower waveform in Fig. 2(d). The locking time is measured from optical packets input to clock buildup. 300-ns locking time was measured in the ~0.3-m loop length. Stronger input optical power reduces the OCR's locking time shown as Fig. 2(e). We also measured locking time against the OCR's loop length by changing the RF cable length, shown as Fig. 2(f). OCR with stronger injection, low losses, higher gain as well as shorter loop length is desired for fast locking time [6].

Fig. 3 depicts single sideband (SSB) noise spectra of main peak of recovered optical clock (with EDFA amplification) using PRBS word length of $2^{31} - 1$ and $2^7 - 1$, respectively (although in laboratory environment, PRBS characteristics of original signal cannot fully be preserved after optical multiplexer). We obtained almost same RMS jitter under 0.6 ps through integrating noise spectra from offset frequency of 100 Hz to 400 kHz. Above 400-kHz offset frequency, first sideband occurs due to low frequency modulation of the packet clocks. This suggests that the effect of the word length is not so significant to the OCR.

Simultaneous clock recovery and reshaping

To demonstrate reshaping capability, the pulsewidth from the gain-switched DBR laser was intentionally broadened from 10 ps to 18 ps. As shown in Fig. 4, data signal was reshaped due to narrow TW-EAM's switch window when comparing the eye diagrams of output and input optical packets. Also, less timing jitter can be achieved under the narrow synchronized window. The standard deviation measured with the sampling scope is 4.2 ps but after the OCR it is reduced to 1.2 ps. Comparing the clocks recovered from ~40-Gb/s input optical packets with narrow and broadened pulsewidth, no obvious differences were observed. Successful operation of the OCR is only determined by the clock tone of input signals.

Simultaneous clock recovery and reshaping

Conclusions

Simultaneous clock recovery and reshaping for 40-Gb/s optical packets is demonstrated for the first time by utilizing an OCR consisting of a TW-EAM-based ring oscillator. The OCR achieves clock recovery within 300 ns and the recovered optical clock has less than 0.6-ps timing jitter. Shorter loop length and stronger injection can reduce the locking time.

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References