Up to 425 GHz All Optical Frequency Down-Conversion Clock Recovery Based on Quantum Dash Fabry-Perot Mode-Locked Laser

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Abstract: We demonstrate that quantum-dash mode-locked laser can perform all optical frequency down-conversion clock recovery up to 425 GHz. We measured 0.3 dB penalty on the optical recovered clock for 170 Gbit/s signal.

OCIS codes: (060.4510) Optical communications, (230.5590) Quantum-well, -wire and -dot devices

1. Introduction

Ultrahigh-speed clock recovery is a key function for future optical communications. Optical transmission systems for use up to 160 Gbit/s require complex arrangements to recover the clock needed for the optical time domain signal demultiplexing of these signals. Mode-locked semiconductor lasers have been employed for sub-harmonic optical clock recovery (OCR) and particularly for the recovery of a 40 GHz clock from a 160 Gbit/s data stream [1]. In a recent work [2], a similar Quantum dash Fabry-Perot mode locked laser diode (QD-FP-MLLD) similar to the one studied in this paper is used for the all optical clock recovery operation. Such a laser, exhibiting an extremely narrow mode-beating spectral linewidth, has previously been shown to be able to recover an optical clock with jitter performances compatible with ITU G285-1 recommendations for 40 GHz clock recovery.

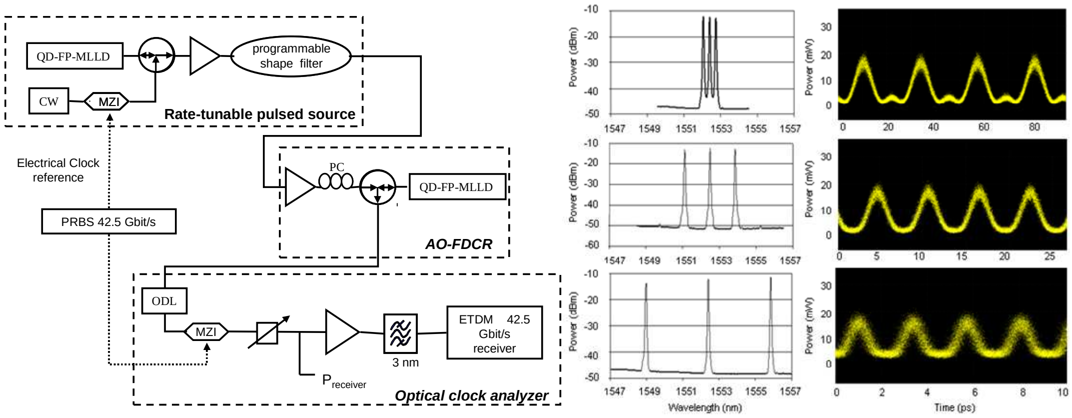
In the present paper, we demonstrate for the first time that a QD-FP-MLLD can also be used as an all optical frequency down-conversion clock recovery (AO-FDCR) up to 425 GHz, corresponding to 10 times the repetition rate of the laser. The quality of the optical clock was assessed through bit error rate (BER) measurements. In a first step, an experiment demonstrates the capability of frequency down-conversion clock synchronization with a rate-tunable pulsed source from 42.5 GHz to 425 GHz. Finally, the AO-FDCR is characterized in system experiment up to 170 Gbit/s.

2. All optical clock frequency down-conversion

In this part, we first investigate the ability of the QD-FP-MLLD to generate a 42.5 GHz clock from a N×42.5 GHz incident pulse stream. The experimental setup is shown in Fig. 1(a). The rate-tunable pulsed source section consists of a first QD-FP-MLLD and of a programmable shape optical filter [3,4].We take advantage of the laser flat gain and broadband emission spectrum (13 nm width at 10 dB) in order to select with the programmable shape optical filter three lines that generate the desired N×42.5 GHz pulse stream. The laser is actively mode-locked thanks to a standard RZ 33% 42.5 GHz optical clock signal generated at 1535 nm by a Mach-Zehnder intensity modulator (MZI). Fig.1(b) shows the optical spectrum and temporal shape of the generated pulse stream for three different frequencies. These traces were obtained thanks to an optical sampling oscilloscope with a time resolution of one picosecond.

The all optical clock frequency down-converter consists of a second QD-FP-MLLD with a peak emission wavelength around 1570 nm followed by an optical filter to eliminate the residual N×42.5 GHz pulse stream. By adjusting the current and temperature of the laser, the repetition frequency can be tuned close to 42.5 GHz. When the N×42.5 GHz pulse stream is injected inside the laser cavity, we obtain a 42.5 GHz recovered clock at 1570 nm. A polarization controller at the AO-FDCR input allows the mode–locking efficiency of the QD-FP-MLLD to be optimized.

In order to assess the all optical down-conversion scheme, the laser output is then modulated at 42.5 Gbit/s by a MZI. An optical delay line (ODL), placed before the modulator, provides a fine tuning of the clock-data phase. The modulator output is directed to an optical receiver for BER measurements which allow to check whether the down-converted recovery clock is correctly locked. In effect, if this were not the case, the BER penalty would be infinity.



a) Experimental setup *b) Optical spectrum and temporal shape of generated clock*

Fig.1. Experimental setup and generated clock for three different frequencies: 42.5 GHz; 170 GHz and 425 GHz

The frequency of the optical signals generated for this experiment can change from 42.5 GHz to 425 GHz when three main lines of the spectrum are selected by the filter as shown in Fig.2. Contrary to the optical time-division multiplexing technique based on interleaving pulses with couplers and delay lines to multiply the repetition rate of the original pulsed source, the optical spectrum of our multi-rate source has no residual spurious spectral components at the fundamental clock frequency spacing of the first QD-FP-MLLD. These spurious lines are suppressed by more than 40 dB. They are too weak to cause a sub-harmonic synchronisation of the AO-FDCR at the original clock frequency.

Figure 2 shows the BER measurements versus the receiver input power when a signal with the N×42.5 GHz pulse stream enters the AO-FDCR. The reference BER curve is obtained by directly connecting the pulse stream generator output tuned at 42.5 GHz to the optical clock analyser block. We can observe that the AO-FDCR is able to lock in the same condition for any frequency signal between 42.5 and 425 GHz and that there is no penalty for BER less than 10^{-8}.

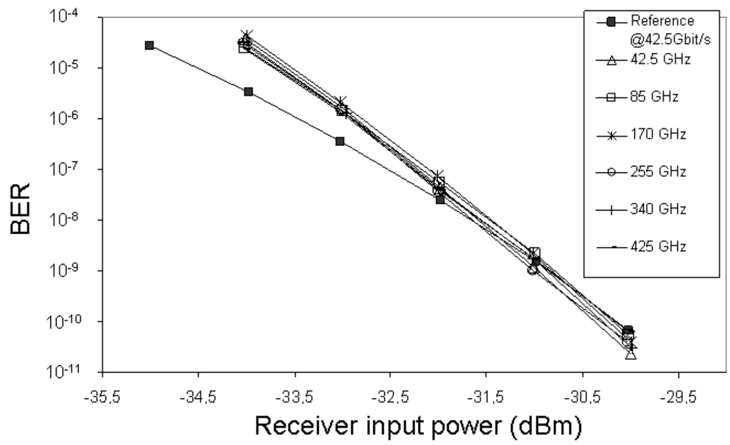


Fig.2. BER results for different frequencies of the transmission optical signal

3. All optical frequency down-conversion clock recovery

This part is devoted to the down-conversion clock recovery performance of the AO-FDCR when an N×42.5 Gbit/s data stream is injected into it. In this experiment (Fig. 3), the first QD-MLLD generates a pulse stream at 42.5 GHz with a full width at half maximum of pulses of 1.5 ps. Then, the pulse stream is modulated through a MZI modulator at 42.5 Gbit/s with a 2^7-1 or 2^{15}-1 pseudo-random binary sequence (PRBS). A bit-rate multiplier (BRM) finally multiplexes four delayed versions of the signal to provide a 170 Gbit/s data stream.

The output of the BRM is injected into the AO-FDCR, which output at 42.5 GHz is connected to our previously described optical clock analyzer set-up.

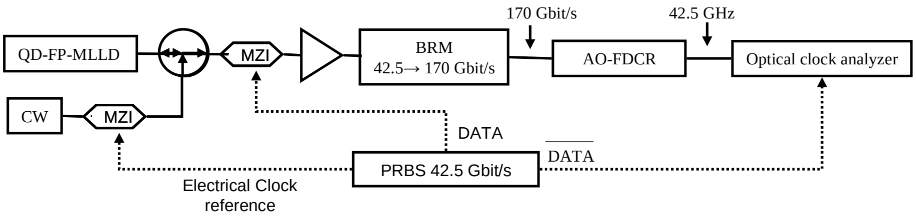


Fig.3. AO-FDCR experimental setup

Figure 4 shows the BER results for both 42.5 Gbit/s (without BRM) and 170 Gbit/s cases. We can see a penalty of only 0.3 dB in comparison with results obtained in section 2 with a pulse stream without PRBS modulation. Moreover, no penalty is observed when the bit rate of data stream is switched from 42.5 to 170 Gbit/s.

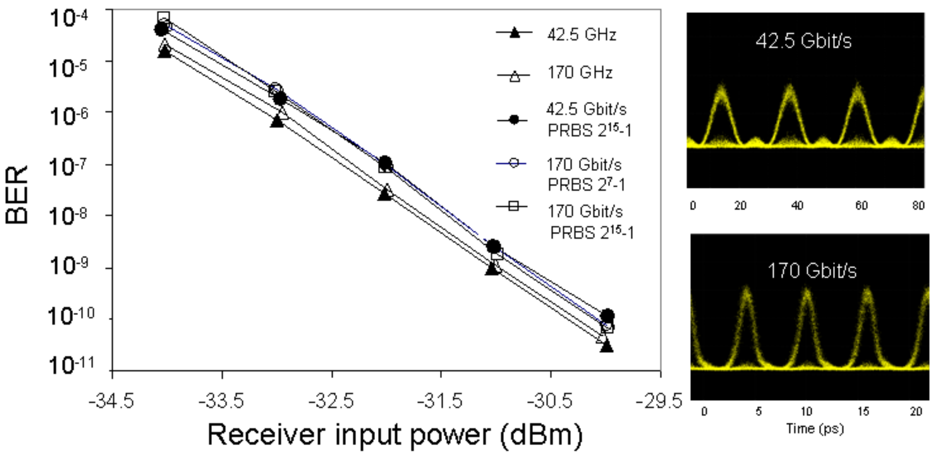


Fig.4. (a) BER results with data stream at 170 Gbit/s

5. Conclusion

In this paper we demonstrate that a QD-FP-MLLD can perform all optical frequency down-conversion clock recovery. We have shown that the AO-FDCR is able to lock in the same condition for any frequency pulse stream between 42.5 and 425 GHz. The quality of the recovered clock is analysed by BER measurement: no penalty is observed for BER less than 10^{-8}. Finally, we have measured a slight penalty of 0.3 dB when a data stream at 170 Gbit/s is injected into the AO-FDCR. These results show the potential of QD-FP-MLLDs to perform both clock recovery and frequency down-conversion functions. QD-FP-MLLDs could be key components for future 400 Gigabit Ethernet network.

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