Using Signal Pre-Distortion to Enhance the Performance of All-Optical Clock Recovery

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ABSTRACT

We investigate a clock enhancement technique using semiconductor optical amplifier based Mach-Zehnder interferometer (SOA-MZI) for all-optical clock recovery with numerical simulations. The simulations determine the optimal operation points of the SOA-MZI for return-to-zero (RZ) and non-return-to-zero (NRZ) inputs, achieving effective clock performance improvement.

Keywords: All-optical clock recovery, Semiconductor optical amplifier, Fabry-Perot filter, clock enhancement

1. INTRODUCTION

All-optical clock recovery is a key technology to enable transparent and cost-effective optical 3R regeneration. Previous research works have demonstrated that all-optical clock recovery can be achieved through extracting the clock spectral components using narrow-band optical filtering with a Fabry-Perot filter (FPF) [1, 2]. The FPF usually has a free-spectral range (FSR) matched to the data bit-rate and a relatively large finesse (typically > 20) [2, 3]. However, when the signal is encoded in nonreturn-to-zero (NRZ) format or the return-to-zero (RZ) pulses are broadened due to fiber dispersion effects, the clock components become weak [4, 5]. This leads to decrease in performance of the recovered clocks. To overcome this drawback, researchers proposed a clock enhancement technique that uses signal pre-distortion in a semiconductor optical amplifier based Mach-Zehnder interferometer (SOA-MZI) [4, 5]. In this paper, we build a simulation model with realistic SOA-MZI parameters and investigate the clock enhancement technique with numerical simulations. Based on the simulation results, we determine the optimal operation points of the SOA-MZI for various input encodings (e.g. RZ and NRZ).

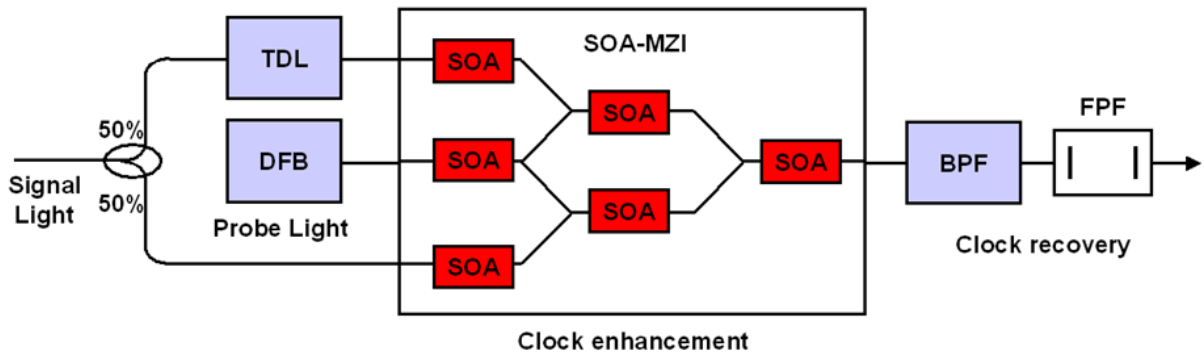

Fig. 1 Setup of clock enhancement and recovery subsystem, TDL: tunable delay line, DFB: DFB laser diode, SOA: semiconductor optical amplifier, BPF: band-pass filter

2. OPERATION PRINCIPLE

Fig. 1 shows the setup of the clock enhancement and recovery subsystem. The SOA-MZI is in a push-pull operation that injects the input signal into both interferometric arms with a relative time delay. The output of the SOA-MZI can be modeled as [6]:

$$I_{out}(t) = I_0[G_1(t) + G_2(t) + 2\sqrt{G_1(t)\cdot G_2(t)}\cdot\cos(\phi_1(t) - \phi_2(t))] \tag{1}$$

where I_0 is the intensity of the probe light, $G_1(t)$ and $G_2(t)$ are the gains probe light get from the two arms, and $\phi_1(t)$ and $\phi_2(t)$ are the phases of the probe lights before interference. We assign the initial gain of the SOA as 10 dB, and the gain recovery time as 25 ps. The 10 Gb/s input signal is encoded with PRBS 2^{31}-1. The signal is pre-distorted in the SOA-MZI and then fed into the FPF for all-optical clock recovery. The FPF has a FSR of 10 GHz and a finesse of 100. The simulations investigate both the RZ and NRZ format, and the full-width at half-maximum (FWHM) is 50 ps for the RZ pulses.

Fig. 2 shows the comparison of the clock spectra with and without clock enhancement using pre-distortion for RZ inputs. Fig. 3 shows the comparison for NRZ inputs. With the same average input power, the clock enhancement improves the carrier-to-noise-ratio (CNR) by 6 and 9 dB for RZ and NRZ inputs, respectively. Moreover, the absolute power of the clock component is also improved, especially for the NRZ input. Fig. 4-5 show the time-domain eye-diagrams and overlappings of the signals and recovered clocks. We can see that the pre-distortion sharpens the clock components in the input signal and reduces both the timing jitter and amplitude fluctuation on the recovered clocks.

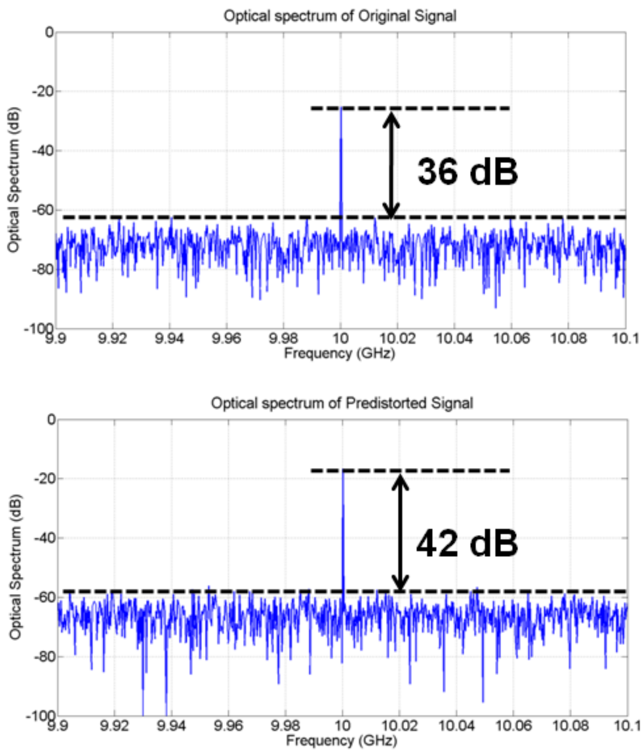

Fig. 2 clock spectrum comparison for RZ input

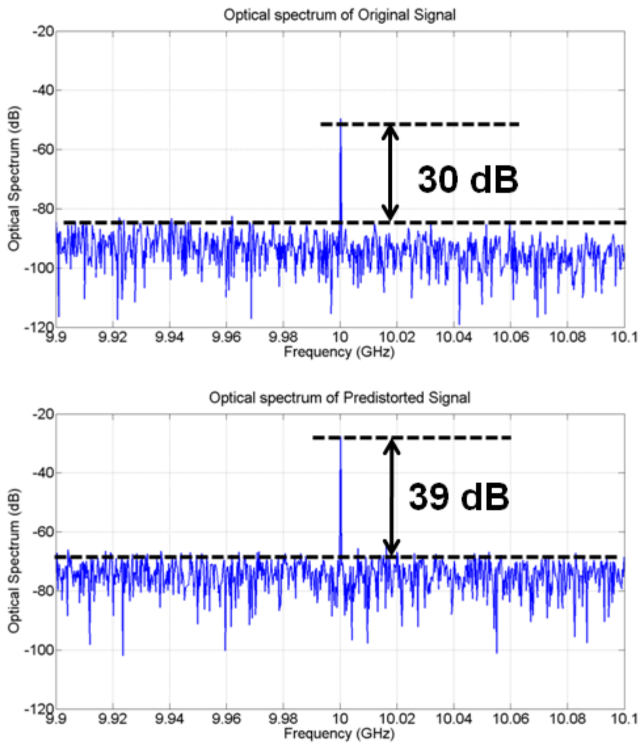

Fig. 3 clock spectrum comparison for NRZ input

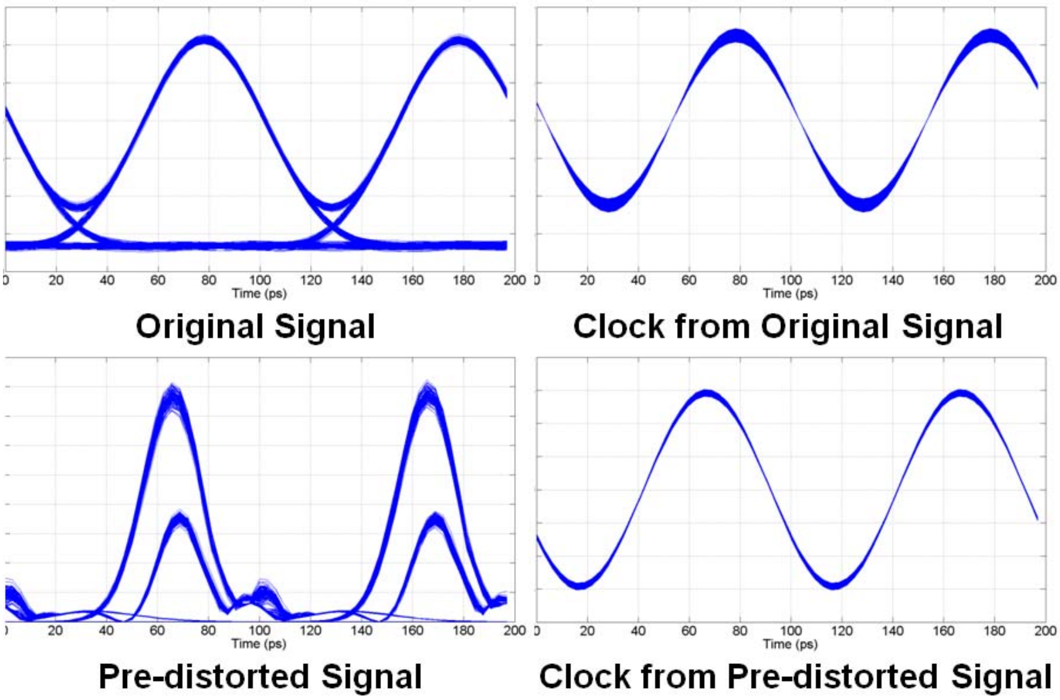

Fig. 4 Time-domain eye-diagrams and overlappings of the signals and recovered clocks for RZ inputs

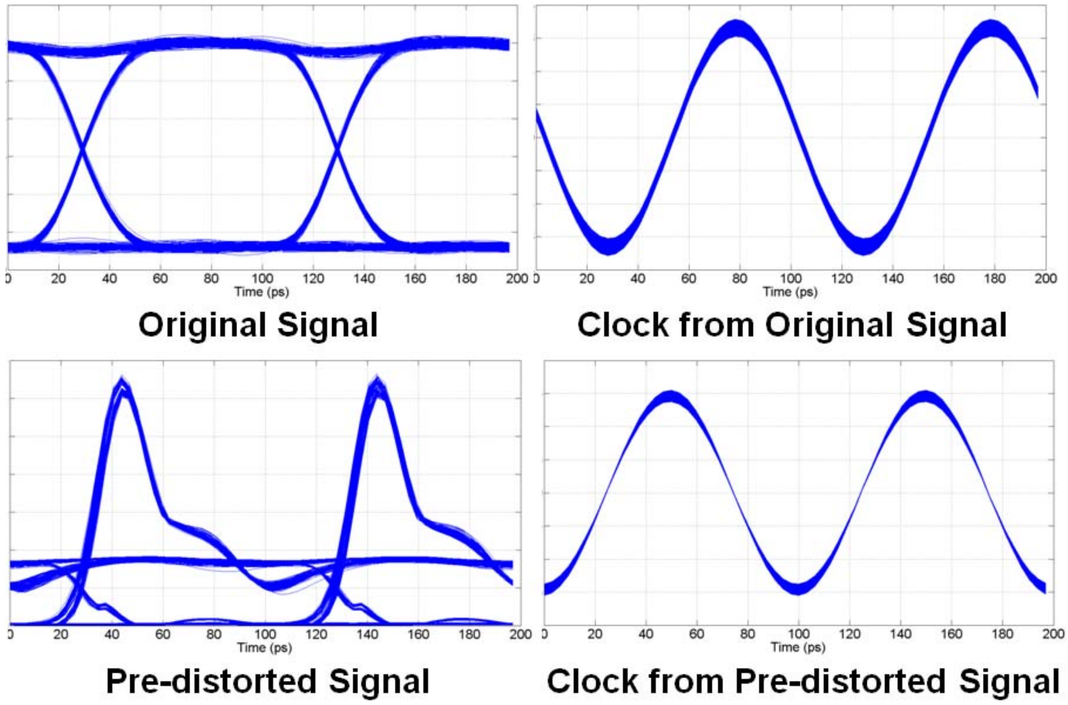

Fig. 5 Time-domain eye-diagrams and overlappings of the signals and recovered clocks for NRZ inputs

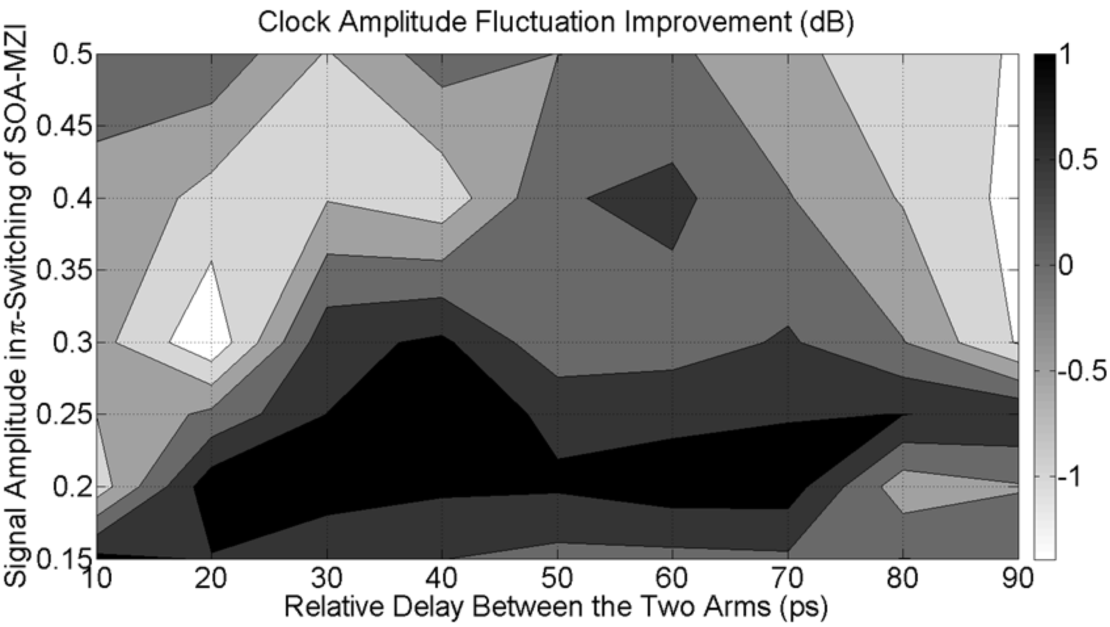

Fig. 6 Contours of clock fluctuation improvement for RZ inputs

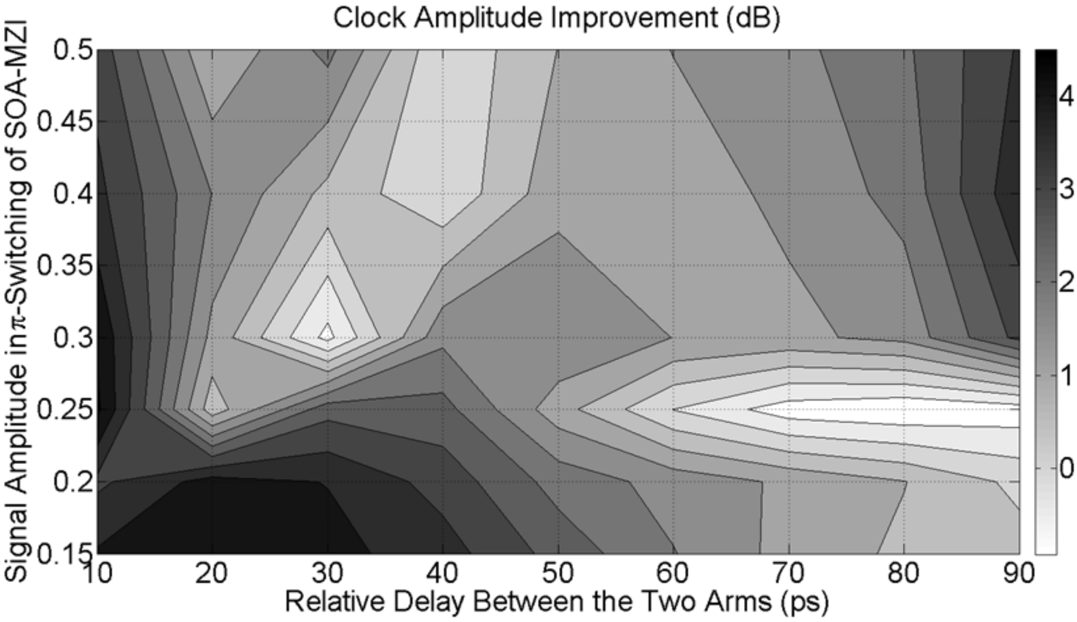

Fig. 7 Contours of clock amplitude improvement for RZ inputs

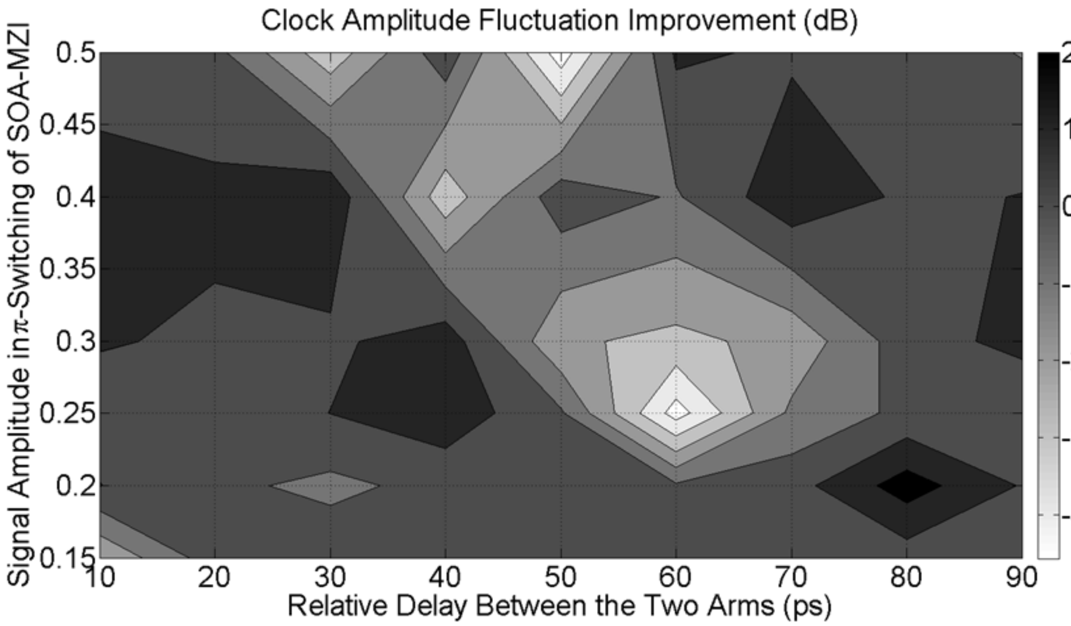

Fig. 8 Contours of clock fluctuation improvement for NRZ inputs

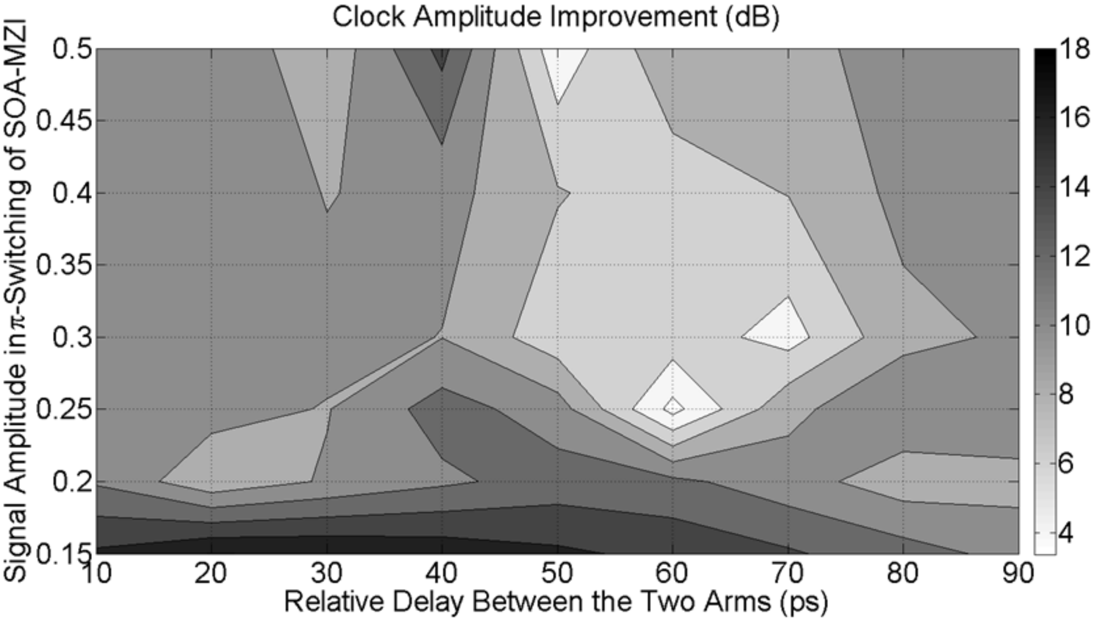

Fig. 9 Contours of clock amplitude improvement for RZ inputs

3. SIMULATIONS AND SYSTEM OPTIMIZATIONS

To determine the optimal operation points of the SOA-MZI for clock enhancement, we scan the signal input power and relative delay between the two SOA-MZI arms in the simulations. The amplitude of the input signal is normalized with the π-switching power (optical power to achieve π phase difference between the two arms) of the SOA-MZI, and the relative delay is changed from 10 to 90 ps. As shown in the contours in Fig. 6-9, the clock enhancement with pre-distortion can not only improve the amplitude of the recovered clocks, but also reduce the amplitude fluctuation. For the RZ inputs, when the signal input power is within [0.15, 0.2] π-switching power and the relative delay is within [20, 30] ps, the amplitude of the recovered clock can be increased by 4.5 dB and the amplitude fluctuation can be reduced by 1 dB. For the NRZ inputs, when the input power is within [0.25, 0.3] π-switching power and the relative delay is within [30, 40] ps, the clock amplitude can be increase by around 12 dB and the amplitude fluctuation can be reduced by 2 dB.

4. SUMMARY

We built a simulation model with realistic SOA-MZI parameters and investigated a clock enhancement technique using SOA-MZI for all-optical clock recovery based on FPF filter. The simulation results showed that the pre-distortion by SOA-MZI could sharpen the clock components in the input signal and reduce both the timing jitter and amplitude fluctuations on the recovered clocks. By scanning the input signal power and relative delay between the two SOA-MZI arms, we determined the optimal operation points of the SOA-MZI for RZ and NRZ inputs and achieved effective clock amplitude improvement and clock amplitude fluctuation reduction.

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