Experimental Demonstration of an All-Optical Clock and Data Recovery Technology for 10 Gb/s NRZ-DPSK Signals

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Abstract: We demonstrate an all-optical clock-and-data recovery technology for 10-Gb/s NRZ-DPSK signals. With a relatively simple configuration, the clock-recovery scheme achieves less than 1.5-ps RMS jitter for signals after fiber transmission. The pattern-dependence of data-recovery is within 0.5-dB at BER 10^{-9}.

Keywords: All optical clock recovery, Differential phase shift keying, Fiber Bragg grating, Wavelength conversion, Fabry-Perot filter

1. Introduction

The optical differential-phase-shift keying (DPSK) modulation with balance detection yields a nearly 3 dB advantage in amplified spontaneous emission (ASE) noise limited fiber transmission systems over conventional on-off keying (OOK) modulation [2]. Besides, due to the constant power in each bit slot, DPSK signals have better tolerance to fiber nonlinearities. Therefore, DPSK modulation becomes an attractive technology for the high-speed and long haul transmission in future optical networks [1-2]. The related enabling technologies associated with DPSK systems, such as clock recovery and optical regeneration, become important. However, there are only a few works reported in these areas. In this paper, we propose and experimentally demonstrate an all-optical clock-and-data recovery technology for 10 Gb/s NRZ-DPSK signals. The data-recovery employs narrow optical filtering based on a fiber Bragg grating (FBG) for phase modulation to amplitude modulation (PM-to-AM) conversion and direct detection. The all-optical clock recovery is achieved with the combination of PM-to-AM conversion using a FBG, clock enhancement using a semiconductor optical amplifier based Mach-Zehnder Interferometer (SOA-MZI), and clock extraction using a Fabry-Perot filter (FPF). With a relatively simple configuration, the proposed scheme achieves stable, polarization insensitive and error-free all-optical clock-and-data recovery for 10 Gb/s non-return-to-zero (NRZ) DPSK signals without and with fiber transmission. To the best of our knowledge, this is the first experimental demonstration of polarization insensitive all-optical clock-and-data recovery for NRZ-DPSK signals.

2. Experimental Description

Fig. 1 shows the experimental setup. The 10 Gb/s pre-coded data signal drives a $LiNbO_3$ phase modulator to generate an optical NRZ-DPSK signal at 1549.3 nm. As shown in Fig. 1(a), the phase modulation produces a constant intensity without any intensity dips. The NRZ-DPSK signal then experiences a 60 km Large Effective Area Fiber (LEAF) transmission. After the fiber transmission, there is one two-stage Erbium Doped Fiber Amplifier (EDFA) and Dispersion Compensated Fiber (DCF) to compensate for the loss and chromatic dispersion. Due to the fact that there is an around 40 ps/nm residual chromatic dispersion, the DPSK signal after fiber transmission shows small amplitude variations (shown in Fig. 1(b)).

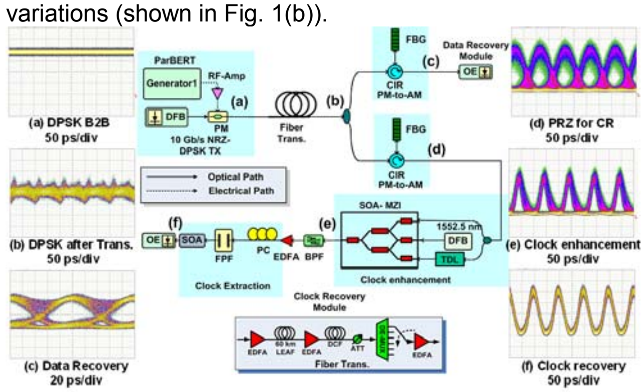

Fig. 1 Experimental Setup, ParBERT: Parallel Bit-Error-Rate Tester, ATT: optical attenuator, BPF: optical band-pass filter, CIR: optical circulator, DFB: DFB laser diode, TDL: tunable delay line, OE: Optical to Electrical Converter, PM: phase modulator, PM-to-AM: phase modulation to amplitude modulation conversion, DEMUX: optical wavelength demultiplexer, (a)-(e) Eye diagrams measured at different locations as labeled in the setup

After the fiber transmission, the optical DPSK signal is split for separate data and clock recoveries. The data recovery module utilizes a fiber Bragg grating (FBG, FWHM = 0.16 nm) to converts the NRZ-DPSK signal to an intensity-modulated signal [2, 4]. The conversion output eye-diagram is shown in Fig. 1(c). In the clock recovery module, another FBG with a FWHM of 0.08 nm converts the NRZ-DPSK signal into a pseudo-RZ (PRZ) format (as shown in Fig. 1(d)) to amplify the 10 GHz clock component in the signal spectrum. This PRZ signal is then launched into the clock enhancement module, where a semiconductor optical amplifier based Mach-Zehnder Interferometer (SOA-MZI) operating in a differential mode enhances the clock component by narrowing down the RZ pulse-width (as shown in Fig. 1(e)). Meanwhile, the wavelength conversion in the SOA-MZI suppresses the signal polarization variation from fiber transmission. Working as a polarization variation isolation interface, the clock enhancement module prevents the input polarization changing from affecting the subsequent processing in the clock recovery. Thus, polarization insensitive all-optical clock recovery from an NRZ-DPSK signal can be achieved. The clock enhancement output travels to the clock extraction module, where a combination of a Fabry-Perot Filter (FPF) and a semiconductor optical amplifier (SOA) performs all-optical clock recovery with amplitude equalization [3]. The FPF has a FSR of 10 GHz and a finesse of 100. The recovered optical clock is shown in Fig. 1(f). Compared to previous proposed scheme in [6], this scheme has a simpler configuration and offers polarization insensitive operation.

3. Experimental Result

The experimental demonstration utilizes different pseudo random binary sequence (PRBS) pattern lengths to evaluate the performance of the all-optical data-and-clock recovery module. By integrating the single-sideband phase noise spectrum of a clock, one can estimate its upper-bound root mean square (RMS) jitter value [5]. Table 1 shows the RMS jitter values measured for back-to-back (B2B) and after 60 km fiber transmission, using PRBS pattern sequence lengths 2^7-1, 2^{15}-1, 2^{23}-1 and 2^{31}-1. All of the RMS jitter values are less than 1.5 ps.

Table 1. Rms jitter value comparison of recovered clock

Rms jitter	B2B (ps)	60 km trans. (ps)
PRBS 2^7-1	0.327	0.522
PRBS 2^{15}-1	1.438	1.472
PRBS 2^{23}-1	1.274	1.413
PRBS 2^{31}-1	1.209	1.274

Fig. 2 shows the clocks recovered from signals after 60 km fiber transmission with different PRBS pattern lengths. All of them are clean with reasonably small amplitude variation (< 1.5 dB).

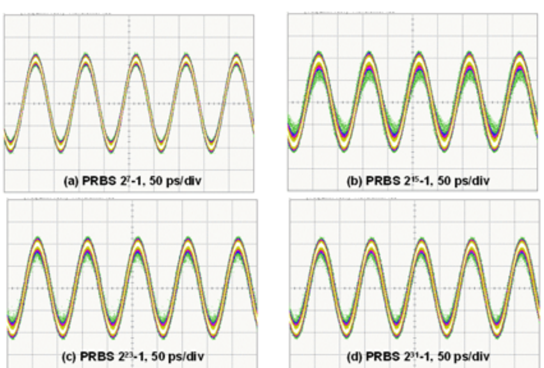

Fig. 2 Clocks recovered from signals after 60 km fiber transmission with (a) PRBS 2^7-1, (b) PRBS 2^{15}-1, (c) PRBS 2^{23}-1, and (d) PRBS 2^{31}-1

Fig. 3 shows the BER measurement results for different PRBS lengths. For the back-to-back cases, the BER measurements are either triggered with a local clock or the recovered clocks. For the signals after the fiber transmission, the BER measurements are either triggered with the clocks recovered by a commercial module (Agilent N4873A) or the all-optically recovered clocks with our method. All BER curves are free of error floor and reach below 10^{-10} with an average receiver power of –18 dBm. The BER results indicate that for the back-to-back cases, there is no significant power penalty when comparing the BER curves measured by the local clock to those by the optically recovered clocks. For the after transmission cases, the similar result can be seen when comparing the performance of the optically recovered clocks to electrically recovered ones. The fiber transmission introduces a 0.7dB power penalty at BER 10^{-9}. The BER curves also indicate that the pattern dependence in terms of receiver sensitivity at BER 10^{-9} is below 0.5 dB for PRBS sequence length changing from 2^7-1 to 2^{31}-1.

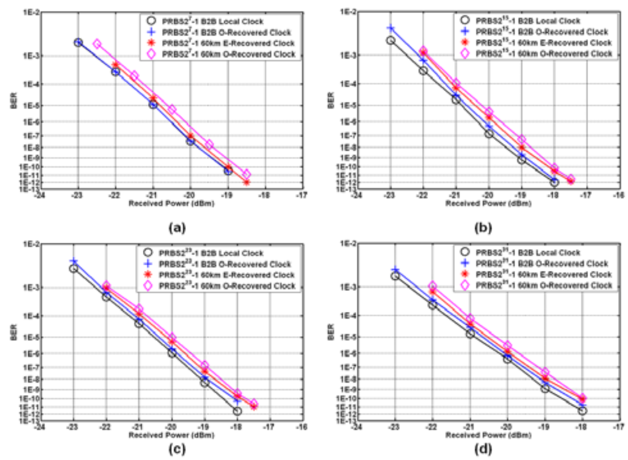

Fig 3 BER measurement results for back-to-back and after 60 km transmission, when the signal is encoded with (a) PRBS 2^7-1, (b) PRBS 2^{15}-1, (c) PRBS 2^{23}-1, and (d) PRBS 2^{31}-1

4. Conclusions

We proposed and experimentally demonstrated an all-optical data and clock recovery technology for 10 Gb/s NRZ DPSK signals. The scheme successfully suppressed the polarization scrambling from fiber transmission, and achieved the stable clock recovery with RMS jitter less than 1.5 ps and error-free date-recovery operation.

5. References

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