transmission system was 20 Gb/s, while the symbol rate was 10 Gbaud (=10 Gb/s). The second MZ modulator was used as a pulse carrier to generate RZ-DQPSK signals. For the 20-Gb/s DQPSK receivers, two 100-ps DIs with two separate balanced receivers are generally required to simultaneously demodulate the two 10-Gb/s data streams contained in the 10-Gbaud DQPSK signal [4]. However, we utilized a single 100-ps DI to demodulate each 10-Gb/s data stream individually by adjusting the differential optical phase between the two DIs by ±π/4 or −π/4. In our experiment, no data encoder circuit was employed. Thus, to allow bit-error ratio (BER) measurements, we programmed the error detector with the expected data sequence.

III. Experimental results and simulation

Fig. 2(a) shows the measured receiver sensitivity penalty (BER=10−9) for 10-Gb/s DPSK signals as a function of optical source and DI. The measured results show that NRZ-DPSK and RZ-DPSK exhibit almost identical penalties when changing the frequency offset. For example, both coding schemes experience a 1-dB penalty in receiver sensitivity when the frequency offset amounts to ±300 MHz. Fig. 2(b) shows the measured sensitivity penalties for 20-Gb/s (10-Gbaud) DQPSK signals. The results show that, like for DPSK systems, the frequency-offset tolerance is almost independent of the pulse characteristics (making up for a factor of 3.5), and (c) the highest impact of optical noise on DPSK systems by a factor of 6 can be attributed to the optical source frequency offsets than DPSK operating at the same symbol rate, and perfect phase modulation (3-dB bandwidth of 2.2 times the symbol rate), an approximate to the probability densities fails in the case of balanced DPSK reception [5].

Fig. 3 shows the simulated receiver sensitivity penalty as a function of optical source frequency offset, normalized to the bit rate, for DPSK and DQPSK, both for NRZ (dashed) and RZ (solid). The simulations assume an optical 4th-order Gaussian filter (3-dB bandwidth of 2.2 times the symbol rate), an electronic receiver bandwidth of 0.6 times the symbol rate, and perfect phase modulation (instantaneous phase shifts), as produced by an MZ modulator biased at its transmission minimum. The simulation results confirm that DQPSK is more sensitive to frequency offsets than DPSK by a factor of 6.

The reasons why DPSK systems are more sensitive to the optical source frequency offsets than DPSK systems by a factor of 6 can be attributed to (a) the reduced DQPSK symbol rate (making up for a factor of 2), (b) the frequency offset tolerance for DQPSK that is caused by the different number of optical symbol phases as well as by the different operating point on the DI transfer characteristics (making up for a factor of 3.5), and (c) the higher impact of optical noise on DPSK reception (reducing the net difference in frequency offset tolerance between DPSK and DQPSK from a factor of 2×3.5=7 to a factor of 6).

IV. Summary

We have assessed, both by measurement and simulation, the frequency-offset tolerance between optical source frequency and delay-interval for DPSK and DQPSK systems. Our results show that DQPSK is about six times more sensitive to frequency offsets than DPSK operating at the same bit rate.

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Real-Time OC-192 All-Optical Bit-Error Monitoring System Using Inverted Wavelength Converter and Optical NOR Gate

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A low cost, simple bit-error monitoring system is realized all-optically using an inverted wavelength-converter and optical NOR-gate with different operating thresholds. Real-time optical monitoring signal is generated which indicates the positions and duration of bit/burst errors in 10 Gb/s signal.

1. Introduction

Real-time bit error monitoring of high-speed optical transmission can be useful for fault management and quality of service in high capacity transport networks. Typical bit error monitoring schemes require expensive optical-electrical-optical conversions and high speed large-scale-integration chip. All-optical implementation of a real time bit error monitoring system is difficult because of the limited signal processing capabilities of current all-optical devices. In this paper, we demonstrate to the best of our knowledge the first real-time all-optical bit error monitoring system at 10 Gb/s using two multi-wavelength injection-locked Fabry-Perot laser diodes (FP-LD) without any high speed electronics. Relatively complex logic operations; two threshold, one NOR, and one OR functions are realized using the two FP-LDs. Both the positions and the durations of the error bits are given in the optical indicator signal generated by the proposed scheme.

2. Operation Principles and Experimental Results

In the proposed all-optical bit-error monitoring system (BEMS), we use two threshold levels, thlow and thhigh, to determine the error bits where thhigh > thlow. If the optical intensity in a bit period is above thhigh (below thlow), the bit period is assumed to contain a correct ‘1’ (‘0’) bit. If the optical intensity falls in between the two threshold levels, the bit period is assumed to contain an error bit. The operation of the BEMS can be realized using the logic operation NOR NOT[TH(1)p], TH(2)p], where TH 1 and TH 2 are threshold functions using the threshold levels thlow and thhigh, respectively. That is, TH(1)p = 1 if p > thhigh; and TH(1)p = 0 if p < thlow, where i = 1, 2, and x = low, high. Note that the input data bit, p, can be in one of three states; 1, E, and 0, where E stands for an error bit. The threshold levels are chosen such that thlow < E < thhigh. Thus TH 1 converts an E into a 1 but TH 2 converts
converts an E into a 0. Figure 1a shows the truth table of the logic operation, NOR [NOT(TH (1)p)], TH (2)p)]. The output of the NOR function is 1 if the input is E but 0 if the input is a 0 or 1. Figure 1b shows the output of the BEMS in the presence of single bit errors and burst errors. The shaded bits in Fig. 1b(i) are the error bits. Figure 1b(ii) gives the output of the NOT gate, i.e., NOT (TH (1)p), and Fig. 1b(iii) gives the output of the NOR gate. The ‘1’ bits in Fig. 1b(iii) identify the error bits contained in Fig. 1b(i). Figure 2 shows the schematic of the experimental setup to demonstrate the BEMS. The corrupted 10 Gb/s NRZ data signal is generated using two 10 Gb/s LN103 modulators on the output of tunable laser (TL 1). Both single-bit errors and burst errors are generated by the modulators with different extinction ratios. The corrupted signals are then split into two parts. One part is injected into a Fabry-Perot laser diode (FP-LD 1) which is used as an inverted wavelength converter. FP-LD 1 implemented the operation of TH 1 and the NOT gate using dual wavelength injection-locking. Besides the input 1542.67 nm (λ 1) data signal, an error signal at 1548.32 nm (λ 2) is also injected into FP-LD 1. The two wavelengths are matched with two different longitudinal modes of FP-LD 1 at the longer wavelength side, with wavelength detunes of 0.18nm and 0.06nm respectively. The threshold level for FP-LD 1 is set to threshold such that an error bit in the data signal is treated as a ‘1’. The power error signals are chosen such that a ‘1’ bit or an error bit in the data signal will injection-lock FP-LD 1. Thus the inverted data signal is obtained at 1548.32 nm in the output of FP-LD 1 with all the error bits converted to zeroes. The other part of the original 10 Gb/s data signal is injected into another Fabry-Perot laser diode (FP-LD 2) synchronized to TH 2 and the NOT gate using multi-wavelength injection locking.4 The threshold level for FP-LD 2 is set to threshold such that an error bit in the data signal is treated as a ‘0’. The powers and detunes (wavelength differences between the signals and the respective FP-LD longitudinal modes) of the three inputs to FP-LD 2 are chosen such that the 1546.11 nm cw signal injection-locks FP-LD 2 only when both the data signal and the FP-LD 1 output are low, i.e., zeroes. The incident power for the input data signal (P data), inverted wavelength converted signal (P data'), and the output wavelength signal (P LD 2) to FP-LD 2 (NOR gate) are 1.43dBm, 0.3dBm and -3.13dBm respectively. Consequently, the ‘1’ bits at 1546.11 nm in the output of FP-LD 2 indicate both the position and duration of any errors in the original signal. Figure 3 shows the spectra of the NOT gate (FP-LD 1) and the NOR gate (FP-LP 2) output respectively. Figure 4a depicts a 10 Gb/s bit-corrupted data signal. The solid arrows identify the single bit errors while the open arrows identify burst errors. The inverted and wavelength converted data signal at 1548.32 nm are shown in Fig. 4b. Note that all the error bits in the original signals are now converted to zeroes. Figure 4c gives FP-LD 2 output at 1546.11 nm. All the error bits in the original signals now appear as ‘1’ bits.

3. Conclusion
In conclusion, we have successfully demonstrated all-optical bit-error monitoring at 10 Gb/s using two mutual injection-locked Fabry-Perot laser diodes. Relatively complex logic operations; two thresholds, a NOT, and a NOR functions are realized all-optically. Since the FP-LDs allow different wavelengths for input and output signals, only one physical path is required for the input signals. The two threshold levels for the optical processing devices can be tuned by varying the wavelength detunes of the FP-LD and the powers of the signal into the FP-LD. Therefore, the scheme can be tailored to monitor the systems with any specific BER.

4. References

Large signal responses to noise in the high speed Hamming encoder (80 MHz) were obtained using the lock-in amplifier. The output signal of the Hamming encoder was found to be very sensitive to noise. A lock-in amplifier was used to recover the true signal from the Hamming encoder output. The lock-in amplifier was used to recover the true signal from the Hamming encoder output. The lock-in amplifier was used to recover the true signal from the Hamming encoder output. The lock-in amplifier was used to recover the true signal from the Hamming encoder output. The lock-in amplifier was used to recover the true signal from the Hamming encoder output. The lock-in amplifier was used to recover the true signal from the Hamming encoder output. The lock-in amplifier was used to recover the true signal from the Hamming encoder output.

Fig. 1. Experimental set-up for jitter analysis of optical clock recovery

The clock pulse trace is analyzed using a novel sampling scope (Agilent 86100B) with a precision time base reference module (Agilent 86107A). This module reduces significantly the inherent jitter of the measurement system by almost an order of magnitude to 200 fs rms, a jitter value much less than conventional scopes with a typical rms-jitter of about 1 ps. Thus detailed jitter analysis and accurate views of 40 Gb/s waveforms by this new generation scope are possible now. To demonstrate the ultimate performance of the optical clock we use at first a fiber ring laser (PrTel) for locking. This actively-mode-locked laser source emits pulses at 40 GHz with very low rms-jitter of 39 fs - derived from single sideband phase noise measurement between 1 KHz and 1 GHz with an rf-analyzer. Using the same technique for characterizing the clock, we found that the signal is synchronized with excellent rms-jitter of 48 fs (Fig. 2a). However, the identical signal measured using the scope results in an rms jitter of 289 fs (Fig. 2b). Please note that jitter calculated by the phase measurements typically gives lower values then that taken by the sampling scope. Phase noise analysis does not regard sufficiently jitter correlated with pattern effects and jittering with simultaneously added amplitude fluctuations. The sampling scope delivers a more comprehensive and a more

1. Introduction
Optical clock recovery is a key function needed for optical signal processing at high speed. Compact semiconductor devices are preferable for application in real systems, they can be integrated e.g. on a silica motherboard. The self-pulsating PhaseCOMB laser (Phase Controlled Mode Beat

Fig. 4. Synchronized temporal profiles for (a) the input 1546.67 nm signal with bit error errors, (b) the inverted λ-converted 1548.32 nm signal and (c) the error indicator signals in 1546.11 nm.

Fig. 3. Spectra for the inverted wavelength converter and the optical NOT gate under single injection-locking of two separate FP-LDs in BEMS.