80Gbits/s DPSK regeneration using an SOA balanced-receiver

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Abstract— **A technique for 2R-regeneration of received RZ and NRZ 80Gbit/s DPSK data is demonstrated using numerical simulations. Balanced gain-compression and amplification inside an SOA are used to reshape and reamplify demodulated DPSK. The technique is tested by wide range of random phase and amplitude noise. It shows >4dB receiver-sensitivity improvement.**

Keywords-optical communications; optical regeneration.

I. Introduction

Encoding digital data as differential phase shifting between adjacent bits in differential phase-shift keying (DPSK) format has recently found many applications in optical communications. The DPSK gives a better receiver-sensitivity than OOK (≅3dB) in case of balanced detection. That allows extended transmission distance and/ or less optical transmitted power [1]. However, the DPSK amplitude and differential-phase could suffer degradations due to transmission nonlinearities [1, 2]. These degradations reduce the transmission distance and increase the received power-penalty. Different techniques have been reported on DPSK regeneration along transmission distance to compensate for such degradations [3-7].

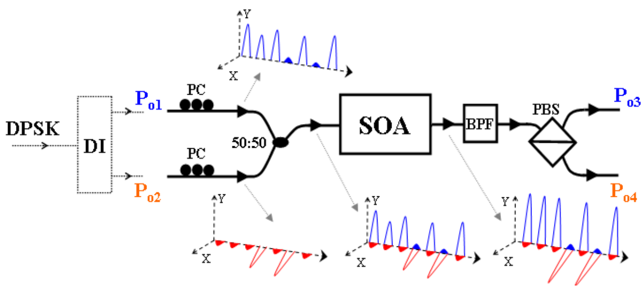

Figure 1. SOA balanced-receiver. Insets shows RZ-DPSK case.

An alternative approach is to improve the DPSK receiver sensitivity by regeneration at receivers. That could reduce transmitted power and thus channel nonlinearities. In this work, a novel technique to regenerate received RZ and NRZ DPSK and improve receiver-sensitivity is demonstrated at 80Gbit/s using numerical simulations. The technique is based on balanced gain-compression and balanced amplification inside a polarization-insensitive SOA, which re-shapes and re-amplifies demodulated DPSK (OOK) data. This balanced configuration is achieved by simultaneous co-propagation of orthogonally-polarized and complementary demodulated OOK streams inside SOA. Thus, the two OOK streams are re-amplified without adding much amplitude-noise (i.e. re-shaped) and the data quality-factor (Q) is improved. The input DPSK phase-noise is inherently suppressed as it is initially converted to amplitude-noise by the one-bit-delay interferometer (DI). The achieved single-ended receiver-sensitivity improvement is better than that of conventional balanced-detection (≅3dB [1]).

II. Principals of Operation

Fig.1 shows a schematic setup for the SOA balanced-receiver together with qualitative plots of propagating signals in case of RZ-DPSK input. The input DPSK is initially demodulated by common one-bit DI. The two demodulated complementary OOK data outputs 'P_{o1}' and 'P_{o2}' co-propagate simultaneously inside SOA. The SOA is simulated using nonlinear pulse-propagation model and optical amplifier rate equations [8]. The modeled SOA has 29dB gain, 10dBm output saturation power, 100ps recovery time, and 6dB noise-figure. The SOA is assumed to be polarization-insensitive (i.e. polarization-sensitivity <0.3dB). The two polarization controllers (PC) are utilized to ensure that 'P_{o1}' and 'P_{o2}' are orthogonal linearly-polarized with each launched along one SOA polarization-axes (X, Y). The SOA two inputs experience same gain and get re-amplified. The SOA gain saturation depends on the total power of both marks and spaces in each bit-period. However, the gain saturation mainly depends on marks amplitude as it has much power than spaces. The power-dependent gain saturation (i.e. gain-compression) suppresses amplitude-noise on marks in each bit-period. The marks amplitude-noise is a combination of input DPSK amplitude-noise in addition to phase-to-amplitude converted phase-noise. The re-amplification and reshaping improves data quality-factor at SOA output. It is important to note that the compressed-gain sees alternating orthogonal-polarized marks during signals co-propagation, which effectively seems as 'all-marks' data pattern because of SOA polarization-insensitivity. Thus the SOA does not introduce pattern-dependence to the output data. A band-pass filter (BPF) is utilized at the SOA output to reduce its ASE noise. Finally, a polarization beam splitter (PBS) is utilized to separate the SOA orthogonally-polarized OOK outputs 'P_{o3}' and 'P_{o4}'.

III. System Performance

The SOA balanced-receiver operation and performance is evaluated using degraded input 80Gbit/s RZ and NRZ DPSK data. The DPSK is running at exactly 83.33Gbit/s (12ps bit-period) and it carries 2^{10}-1 PRBS data at 1550nm. The short PRBS is chosen to reduce the required simulation time. The Gaussian pulse-width in case of RZ-DPSK is 4ps. A one-bit-delay Mach-Zehnder interferometer (MZI) is chosen as a DI in these simulations. The DPSK average input power is set to 5dBm, and the BPF bandwidth is 1.32nm. The DPSK is degraded with simultaneous random differential phase-noise and amplitude-noise. The differential phase-noise is Gaussian with zero mean and standard deviation '$\sigma_{\Delta\phi}$'. The random amplitude-noise is also Gaussian with zero mean and it affects the input DPSK optical signal-to-noise ratio ($OSNR_D$). The degraded DPSK data quality is estimated from the demodulated OOK eye-histograms which carry both input amplitude-noise and phase-to-amplitude converted noise. The quality-factor of the demodulated data is evaluated from the OOK eye-histograms by examining each data bit [9].

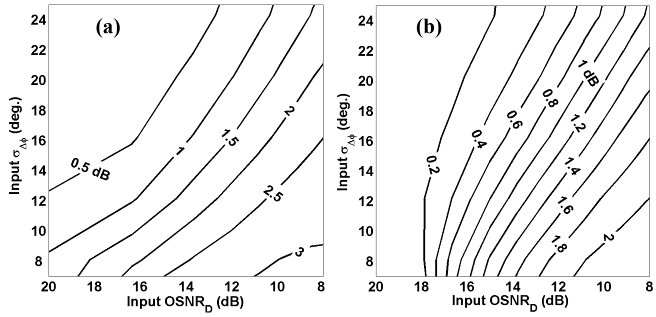

Figure 2. 2-D contour plots of ΔQ for: (a) RZ-DPSK, (b) NRZ-DPSK.

Fig. 2 shows the quality-factor improvement (ΔQ) in case of input RZ-DPSK (a) and NRZ-DPSK (b) for wide range of input noise. The input differential phase-noise '$\sigma_{\Delta\phi}$' ranges from 7^o to 25^o, whereas input $OSNR_D$ ranges from 20dB to 8dB. The Q always improves at SOA balanced-receiver output even for small input noise. That is because the marks standard-deviation is reduced by balanced gain-compression whereas data is re-amplified without pattern-dependence. Thus the quality-factor always improves (i.e. ΔQ is positive) for the entire tested noise range. Also, the Q improvement indicates that the relatively long SOA recovery-time (100ps), compared to the data bit-period (12ps), is uncritical for proper operation at 80Git/s. This is because co-propagation of complement orthogonally-polarized streams allows marks to exist in each bit-period and thus no pattern dependence is introduced. As shown in Fig. 2, the Q improvement increases as the $OSNR_D$ reduces, because more input amplitude-noise is suppressed by gain-compression inside SOA. However, the Q improvement reduces as the phase-noise ($\sigma_{\Delta\phi}$) increases, as the OOK extinction-ratio at DI output becomes smaller. Therefore, the receiver capability to reduce input amplitude-noise is better than that for converted phase-to-amplitude noise.

The received data probability-of-error (i.e. Bit-error-ratio) is evaluated at 80Gbit/s for RZ and NRZ DPSK in case of single-ended and balanced detection before SOA and at the system output, Fig. 3. The $OSNR_D$ of received DPSK is degraded using an attenuator followed by an EDFA before the SOA balanced-receiver. The BER is estimated by carefully analyzing the received marks and spaces probability-density functions [2]. For the case of RZ-DPSK, the estimated improvement of receiver-sensitivity at 10^{-9} BER (onset of error-free), compared to the single-ended input, is ≅4.6dB in case of single-ended output and ≅7dB in case of balanced-detected outputs. For the case of NRZ-DPSK, the estimated improvement is ≅4.2dB in case of single-ended output, and ≅5.6dB in case of balanced-detected outputs. Although the technique does not correct bit-errors (i.e. mark or space flipping), it re-amplifies received OOK data without adding much amplitude-noise, which improves overall optical signal-to-noise ratio and thus receiver-sensitivity.

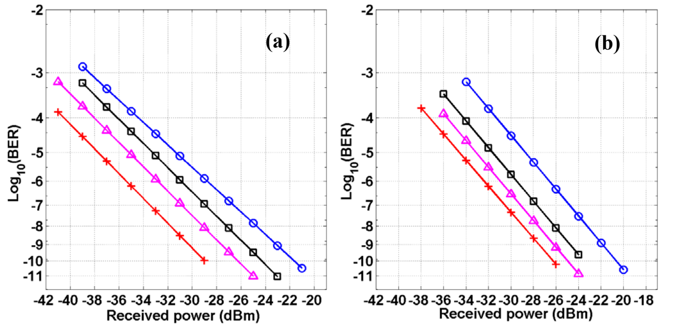

Figure 3. 80Gbit/s BER of demodulated (a) RZ-DPSK, and (b) NRZ-DPSK in case of: single-ended input (circles), balanced-detected inputs (squares), single-ended output (triangles), and balanced-detected outputs (plus).

IV. CONCLUSIONS

A single polarization-insensitive SOA is utilized to improve receiver-sensitivity for 80Gbit/s RZ (NRZ) DPSK data using balanced gain-compression and amplification. The single-ended receiver-sensitivity improvement is better than common balanced-detection technique. The SOA long recovery-time proves to be uncritical for proper operation. The receiver could be easily implemented by any kind of DI and commercially available components. It also could be monolithically integrated to reduce the system overall footprint and cost.

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