EXPERIMENTAL STUDY OF RESHAPING RETIMING GATES FOR 3R REGENERATION

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Abstract: The linear degradation of the bit error rate as a function of the number of regenerators is experimentally observed, with an optoelectronic or with an original all-optical 3R repeater. We demonstrate that Q factor measurements are not suitable for a correct assessment of optical links incorporating 2R or 3R regenerators.

1. INTRODUCTION

Some optoelectronic and all-optical regenerators enabling Re-amplification, Reshaping (2R) and Re-timing (3R) have shown their capability to ensure high bit-rate ultra-long haul transmission systems [1]. Noise distribution and Bit Error Rate (BER) evolution through this kind of device are of great interest to understand basic features of regeneration. In this paper, we show experimentally the BER evolution through different kinds of Non Linear Gates (NLG). We finally compare Q factor and BER measurements in optical transmission links including 3R regenerators.

2. EXPERIMENTAL SET UP

Experiments were carried out with an optical or with an optoelectronic (O/E) regenerator in order to compare two types of 3R regenerators. One is ideal (the optoelectronic one) which presents a step-like shape of the transmission versus input power characteristics, while the other one (the optical regenerator) presents a smoother S-shape. Both regenerators have the same O/E retiming device to ensure 3R regeneration.

2.1 Transmission experiment

The 10 Gbit/s transmission experiment is carried out with a 100 km recirculating loop composed of two 50 km Non-Zero Dispersion Shifted Fibre (NZDSF) spans, with chromatic dispersion of 4ps/nm/km. The fibre link dispersion is compensated (DCF). Figure (1) shows the experimental set-up of the recirculating loop.

Losses are compensated by Erbium Doped Fibre Amplifiers (EDFA) and counterpropagating Raman pumping ensuring a low noise accumulation line. The transmitter consists of a 2^{15}-1 pseudo-random bit sequence combined with a logical gate which produces an RZ electrical signal. This signal modulates the optical 1552 nm source thanks to a $LiNbO_3$ modulator which produces a 50 ps full width at half maximum signal. The signal is injected into the recirculating loop thanks to Acousto-Optic Modulators (AOM).

Noise is artificially included in the loop using an Amplified Spontaneous Emission source (ASE) in order to degrade the Optical Signal to Noise Ratio (OSNR) in front of the regenerator. That is necessary to measure a BER in regenerated signal experiments [2].

A polarization scrambler (polarization modulation frequency ~ 1 MHz) is placed in front of (in the optical case) or behind (in the optoelectronic case) the regenerator in order to take polarization effects into account.

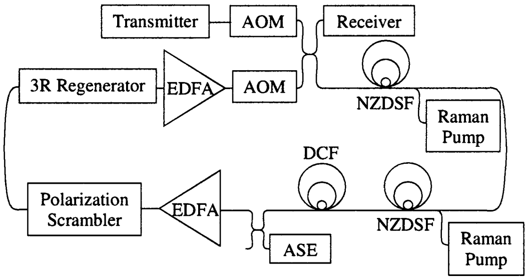
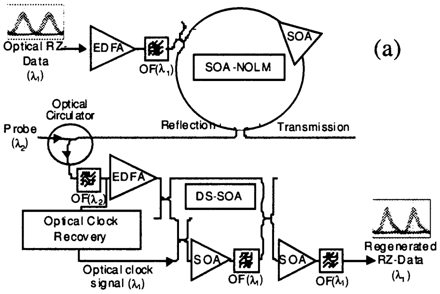


Fig. 1: Recirculating loop.

2.2 Optical regenerator's architecture

The optical regenerator is made of two SOA-based wavelength converters. The first converter consists of a Non-Linear Optical Loop Mirror whose non-linear element is a SOA (SOA-NOLM) [3]. The second wavelength converter is a Dual Stage of SOA (DS-SOA) [4]. Figure (2a) represents the all-optical regenerator scheme.



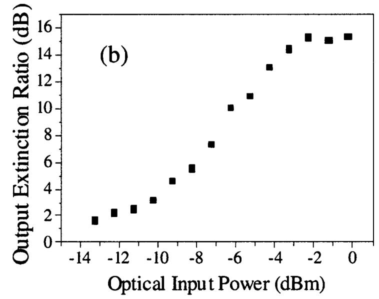


Fig. 2a: All-optical regenerator architecture.

Fig 2b: Output extinction ratio as a function of input power with an input extinction ratio of 15 dB.

The SOA-NOLM is based on a Sagnac interferometer which is intrinsically more stable than all-fibre Mach-Zehnder Interferometers (MZI) provided that fibre arms are short enough. In our case, polarization maintaining fibres are used in order to improve the stability.

Regeneration with NOLM has already been investigated [5] but never, to our knowledge, in a reflective configuration. This allows a better stability with regard to the phase effects and a data output inversion which reduces the converter's polarization dependence.

The DS-SOA as the second wavelength converter stage is an original architecture. In addition to converting the signal back to the initial signal wavelength and to creating a second data output inversion, it improves the output extinction ratio by more than 4 dB. Moreover, the DS-SOA is composed of low polarization sensitivity SOA (0.5 dB) from Alcatel. Consequently, combined with the SOA-NOLM, this results in a polarization insensitive reshaping gate.

The extinction ratio of the overall regenerator is 14 dB for a minimum input extinction ratio of 8 dB. Figure (2b) shows the output extinction ratio versus input power characteristics of the global regenerator that presents an S-shape required for reshaping [6].

2.3 Optoelectronic regenerator architecture

The optoelectronic regenerator has a classical architecture presented on figure (3). It is composed by a 10 GHz PhotoDiode (PD) feeding a Broadband Amplifier (BA) followed by a limiting amplifier. One output of the amplifier is used to recover the clock, the second one feeds the Decision Flip-Flop (DFF). After being amplified by a broadband amplifier, the reshaped and retimed electrical signal finally modulates a local DFB laser through a $LiNbO_3$ modulator.

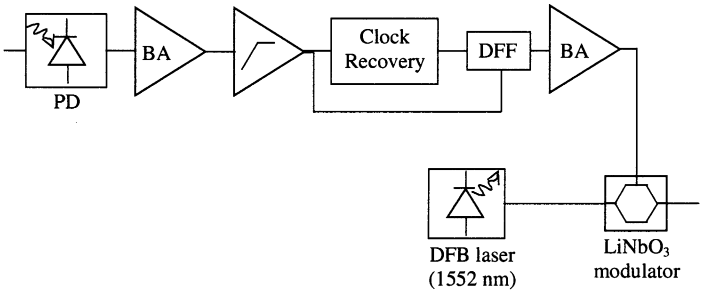


Fig. 3: Optoelectronic regenerator architecture.

3. BIT ERROR RATE EVOLUTION THROUGH A RESHAPING RETIMING GATE

We experimentally show BER evolution with the number of laps for the first time to our knowledge with the two regenerators described above. Results are presented on figure (4) with an OSNR of 17 dB (measured on 0.1 nm). Through the ideal gate (the step function), as initially theoretically reported in [7], the BER in a transmission line with regenerators, linearly increases with the number of concatenated regenerators:

$$BER \approx N \cdot \exp(-k \cdot OSNR) \qquad (1)$$

with N the number of laps, k a suitable constant and OSNR the Optical Signal to Noise Ratio at first lap.

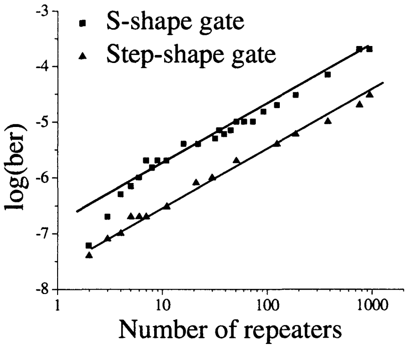


Fig. 4: Experimental BER evolution as the number of laps for an initial OSNR of 17 dB (measured on 0.1 nm).

Through the S-shape NLG, such a linear evolution is observed after about ten laps, this can be explained by the fact that when concatenating the S-shape gate ten times, it tends toward a step function as the transfer function is raised to the tenth power.

Consequently the BER is strongly dependent on the OSNR in front of the first regenerator. The key point will then be to locate the repeater at an early enough stage in order to match a targeted BER for a given link length.

4. Q FACTOR AND BER THROUGH A NON LINEAR GATE

The BER is commonly expressed as a function of the Q factor as:

$$BER = \frac{1}{2} \cdot erfc\left(\frac{Q}{\sqrt{2}}\right) \qquad (2)$$

When the BER is not directly measurable (typically $BER<10^{-10}$), it is deduced from the Q factor measurement [8]. Pertinence of BER measurement deduced from Q factor measurement is studied in that part.

BER was studied as a function of decision threshold at different points of the transmission link. Experimental results are presented on figure (5).

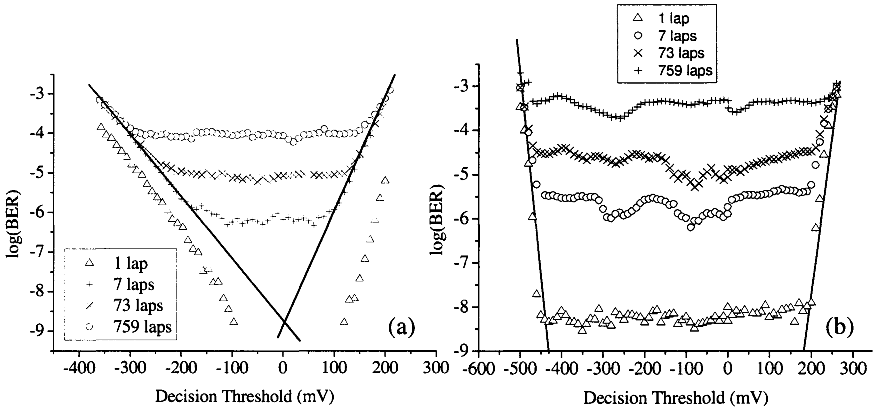


Fig. 5: BER evolution as a function of decision threshold with the all-optical (a) and the optoelectronic (b) regenerators.

The first thing to be noticed is that the BER reaches a plateau, consequently the BER is almost independent of the decision threshold, and the decision is taken by the regenerator through a NLG.

Secondly, in the S-shape case, the plateau width becomes broader as the number of laps increases, namely as the gate tends to a step-like shape. This is the reason why in the step-like shape case, the plateau width remains identical.

On figure (5), extrapolation of the sides is plotted to deduce the Q factor. This measurement would have led to the same deduced BER value, whereas the direct BER measurement leads to an increase of one decade when the lap number is multiplied by ten. As a consequence, we can conclude that Q factor measurement is inadequate to deduce BER evolution as soon as non linear gates are introduced in the transmission line.

5. CONCLUSION

Signal degradation through different non linear gates was investigated experimentally in this paper. The linear degradation of the BER as a function of the number of regenerators was observed, as predicted by the theory, with an optoelectronic or with an original all-optical 3R repeater. Then, to enhance transmission performance, repeaters must be located early enough in the line in order to reach a targeted BER at the link end-side. Also a BER versus decision threshold study leads to the conclusion that Q factor measurement is not an adequate assessment way for optical transmission links including 2R/3R regenerators.

ACKNOWLEDGMENTS

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