# Low-Power Colorless All-Optical 2R Regeneration of 25 Gb/s NRZ Signals using a Standard DFB Laser

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**Abstract**: We demonstrate the first all-optical 2R regeneration of 25 Gbit/s NRZ data based on hysteresis in a DFB laser. The scheme results in BER improvement, exhibits low power consumption and is effective after fiber transmission.

**OCIS-codes**: (140.3490) Distributed-feedback lasers; (250.4745) Optical processing devices

## 1. Introduction

All-optical transparent networks suffer from noise accumulation which severely limits the cascadability of all-optical network nodes. 2R regeneration can be used to significantly reduce the noise on a signal within the optical domain. Several schemes have been reported in the past such as those based on interferometers [1] or self-phase modulation [2]. The disadvantage of most of the previously reported schemes is their high power consumption, complex structure, wavelength dependence or limitation to regenerate only return-to-zero (RZ) signals.

In this paper, we present the use of a standard (non-optimized) DFB laser diode as a 2R regenerator for 25 Gb/s non-return-to-zero (NRZ) signals. The regenerator is wavelength independent and requires only 0.6 W of operational power (incl. cooling), which makes the scheme simpler and more power efficient than opto-electronic regeneration, which typically requires several watts. The underlying effect is a hysteresis in the amplification characteristic of light injected at a wavelength outside the stopband of the DFB grating. This hysteresis is due to a spatial hole burning induced nonlinearity [3], which has been used before to demonstrate all-optical flip-flop operation [4] and packet switching [5]. To the authors' knowledge, this is the first demonstration of all-optical high-speed regeneration using hysteresis effects. We also show that the regeneration is still effective after transmission over a 160 km dispersion-compensated fiber link. Its high speed makes the device interesting for use in 100 Gb Ethernet applications, e.g. by combining a DFB laser array with AWG (de)multiplexers. A similar configuration could even be used for multichannel 40 Gb/s operation after device optimization.

In electronics, the decision circuit of repeaters is often implemented using hysteresis effects (e.g. Schmitt-Trigger) to increase their tolerance towards noise. To the authors' knowledge, an all-optical 2R regenerator scheme based on hysteresis has thus far not been proposed. The conventional 2R regeneration schemes have a single static decision characteristic which is only effective in improving OSNR and reducing subsequent increase of BER. However, these schemes cannot, in principle, improve the BER itself due to the single-threshold nature of the decision characteristic. As demonstrated in [6-7], a real improvement in the BER can only be done by 'Class II regenerators' having a different transfer function for the ones and the zeros. The only scheme proposed thus far to improve the BER relies on self-phase modulation (SPM) in a nonlinear fiber [2,7], but that scheme has the disadvantage of requiring very high optical input powers (typically hundreds of mW). Here, the hysteresis fulfills the condition of different transfer function for ones and zeros and the concept is demonstrated with an improvement of the BER floor by a factor of 50.

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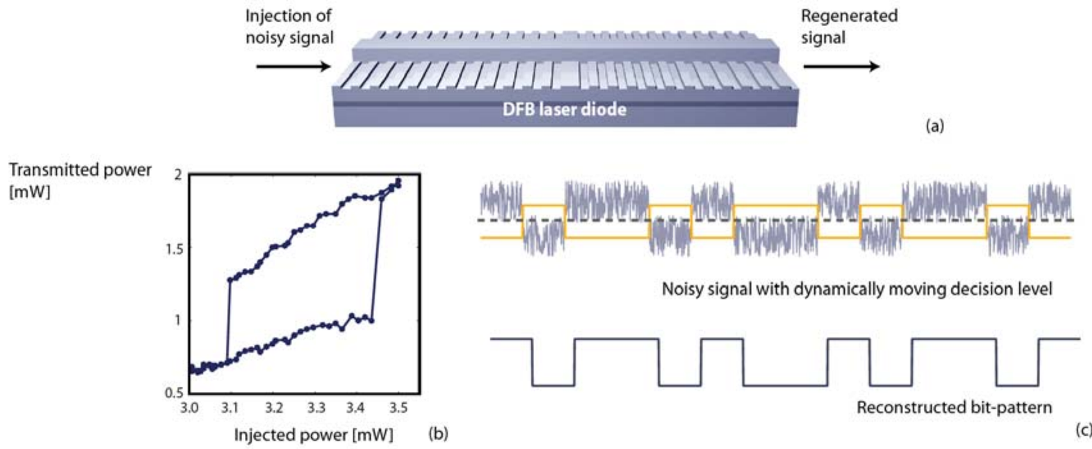


Fig. 1: (a) Schematic of concept for all-optical 2R regeneration using a single DFB laser. (b) hysteresis in the transmission characteristic of the regenerator; (c) original bit pattern with noise and the dynamical moving decision level due to hysteresis (orange).

## 2. Concept

An intuitive approach to understand the concept for the novel regeneration scheme is illustrated in Fig. 1. A noisy bit pattern with a wavelength outside the stopband of the DFB grating is injected in the laser (Fig.1a). There, it is subjected to an amplification with a hysteresis characteristic due to spatial hole burning effects in the DFB laser. The measured (static) characteristic is depicted in Fig. 1b. Because of the hysteresis, there is not one single decision level as in standard regeneration techniques, but the decision level (orange) moves dynamically together with the injected signal as illustrated in Figure 1c. The use of hysteresis results in a higher tolerance on the noise levels than would be possible in a standard regeneration scheme.

## 3. Experimental results

We demonstrate the concept using a standard DFB laser device provided by Alcatel-Thales III/V labs. A 25 Gb/s non-return-to-zero (NRZ) pseudo-random bit-sequence (PRBS) of $2^{31}$-1 bits at a wavelength of 1543 nm is sent consecutively through an attenuator and EDFA to control the optical signal-to-noise ratio (OSNR). The light is combined with a holding beam at a different wavelength (1546 nm), which is used to adjust the power levels of the

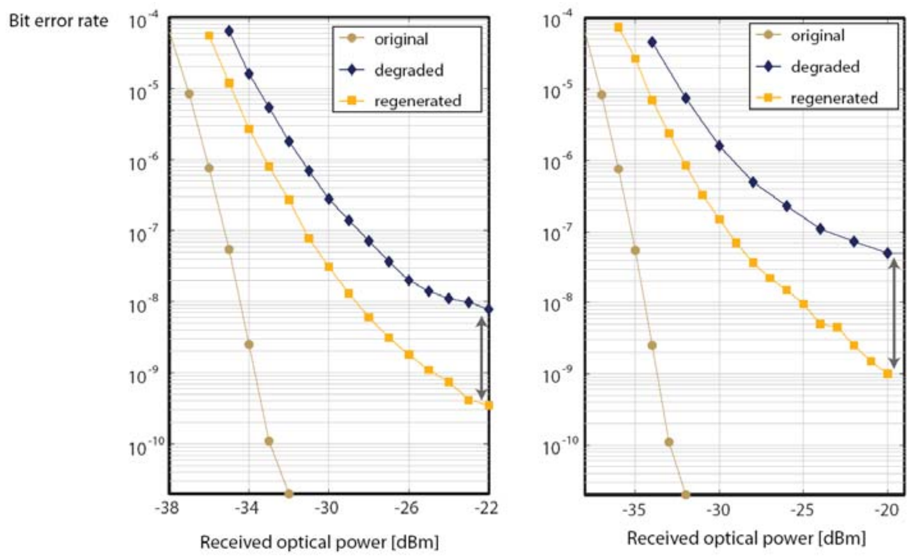


Fig.2: BER versus received optical power for input OSNR of 17.6 dB (left; output OSNR 19.8 dB) and 16.9 dB (right; output OSNR 19.2 dB)

hysteresis to the power of the incoming signal but is not strictly necessary. A λ/4-shifted DFB laser with AR-coated facets is used as regenerator for this experiment. The laser is biased at 150 mA, operates at a wavelength of 1553 nm, has an estimated κL of 1.6 and a length of 400 μm. Using an optical band-pass filter (OBPF) to separate the transmitted light from the lasing light, the BER diagrams of Fig. 2 can be measured by sweeping the attenuator at the input of the pre-amplified receiver. It can clearly be seen that the BER of the regenerated signal is improved compared to that of the degraded signal. One can observe a clear improvement in the BER floor by a factor of 20 to 50, depending on the input OSNR.

Because semiconductor devices can introduce chirp to the signal, we also transmitted the regenerated signal over a dispersion managed link made of 2 times 80 km standard single mode fiber and matching lengths of dispersion compensating fiber. The regeneration is still effective as shown in Figure 3.

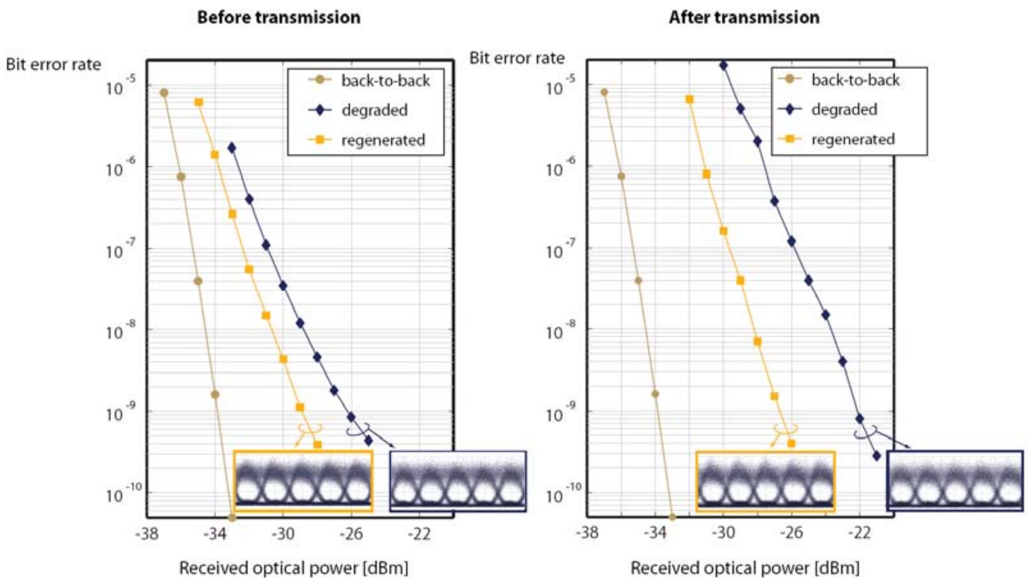


Fig.3: BER diagram before and after transmission through a 160 km dispersion compensated fiber link (input OSNR 18.3 dB)

## Conclusion

We demonstrated a low power, colorless technique for all-optical 2R regeneration of 25 Gb/s NRZ signals based on a hysteresis in the transmission characteristic in a standard DFB laser. Further device optimization could lead to even faster operation (e.g. 40 Gb/s).

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