Calculate BER Improvement due to Nonlinear Regenerators

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Abstract *Use the method we developed recently we calculate the bit-error-rate (BER) improvement as a function of transmitter extinction ratio and the optical link noise parameter.*

Introduction

Various optical regeneration techniques have been proposed and demonstrated [1]-[3] in order to eliminate noise, crosstalk, and signal distortion. All-optical 2R regeneration based on polarization rotation induced by nonlinear birefringence in a semiconductor optical amplifier was recently demonstrated [4] with an improved extinction ratio of 15dB for an input extinction of 5dB. The operating principle of such regenerators relies on the nonlinear input-output transfer characteristic. Recently we proposed a new method to evaluate the performance of a regenerator [5]. With this method in this paper we calculate the bit-error-rate (BER) improvement as a function of transmitter extinction ratio and the optical link noise parameter.

Calculation

We consider an optical transmission link of length L. The transmitter in the system is assumed to have a finite extinction ratio. A nonlinear regenerator is set at position l between the transmitter and the receiver. The system model is illustrated in Fig. 1.

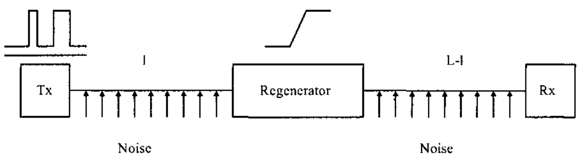

Fig. 1. System model.

The regenerator transforms the input signal x into an output $f(x)$

$$\bar{x} = f(x). \tag{1}$$

Because of the noise accumulation, the probability that a signal and noise will

appear at a given level x is a function of the propagation length. Let $P_0(x,l)$ ($P_1(x,l)$) be the probability of getting a signal at a level x in the position l when the symbol ZERO (ONE) is sent from a transmitter, and let $P^N(y,l)$ be the probability of finding additional noise at a level y after the signal has travelled over a distance l. Assuming that the ZERO and ONE symbols are equally probable, in the absence of a regenerator in the optical link, the BER can be represented by

$$BER_N = \frac{1}{2}\int_D^{\infty} P_0(x,L)dx + \frac{1}{2}\int_{-\infty}^{D} P_1(x,L)dx . \tag{2}$$

The first (second) term is the contribution of the ZERO (ONE) rail. D is the decision level. When a regenerator is used, from the probability theory, the BER contribution of the ZERO rail becomes

$$BER_{R0} = \frac{1}{2}\int_{-\infty}^{\infty} \widetilde{P}_0[g(\bar{x}),l]\left|g'(\bar{x})\right| \quad \times \int_{D-\bar{x}}^{\infty} P^N(y,L-l)dyd\bar{x} . \tag{3}$$

where $\widetilde{P}_0[g(\bar{x}),l]\left|g'(\bar{x})\right|$ is the probability of finding the output of the regenerator at a level $\bar{x}$ when the transmitter sends out a ZERO symbol, $P^N(y,L-l)$ is the probability of finding an additional noise in the second interval $L-l$ at a level y, and $g(\bar{x})$ is the inverse function of the nonlinear transfer function. Similarly, the BER contribution of the ONE rail can be written as follows

$$BER_{R1} = \frac{1}{2}\int_{-\infty}^{\infty} \widetilde{P}_1[g(\bar{x}),l]\left|g'(\bar{x})\right| \quad \times \int_{-\infty}^{D-\bar{x}} P^N(y,L-l)dyd\bar{x} , \tag{4}$$

where $\widetilde{P}_1[g(\bar{x}),l]\left|g'(\bar{x})\right|$ is the probability of finding the output of the regenerator at a level $\bar{x}$ when the transmitter sends out a ONE symbol. Using equations (3) and (4), we obtain an optimal BER

$$\min_{0\le l\le L}\{BER_{R0} + BER_{R1}\}, \tag{5}$$

where $\min\{x\}$ is the minima of x. The optimal position of the regenerator is l_o and it provides the best BER value given by equation (5). The BER improvement attributable to the regenerator is

$$\log(BER_N) - \log(\min_{0\le l\le L}\{BER_{R0} + BER_{R1}\}) \tag{6}$$

The method described here can be generalized to a situation in which more than one nonlinear regenerator is placed in the optical link. However, the calculation is much more complicated than if a single regenerator is used. In the following part of

the paper we will limit ourselves to a single regenerator.

We assume that these probability distribution functions have a Gaussian form, its standard deviation σ is a function of l

$$\sigma = a\sqrt{l}\ , \tag{7}$$

and a is a constant. We also assume that the nonlinear transfer function has the form [4]

$$\bar{x} = f(x) = \begin{cases} \gamma \cdot x & x < 1/2 \\ \gamma \cdot (x-1) + 1, & x > 1/2 \end{cases}, \tag{8}$$

Using the method we proposed recently, we obtain

The BER improvement is defined by

$$\Delta \log(BER) = \log(BER_{N0} + BER_{N1})\ - \log(BER_{R0} + BER_{R1})\ . \tag{9}$$

In Fig. 1 we show the BER improvement, $\Delta \log(BER)$, as a function of the extinction ratio when the standard deviation is set at 0.1. This noise level is set to give a BER of 7.42×10^{-7} without regenerator for an extinction ratio equals 20dB. When a regenerator is used, the BER is improved to 5.18×10^{-12}. Then, we set $l/L = 0.5$ to calculate $\Delta \log(BER)$ as a function of $a\sqrt{L}$. The result is shown in Fig. 2.

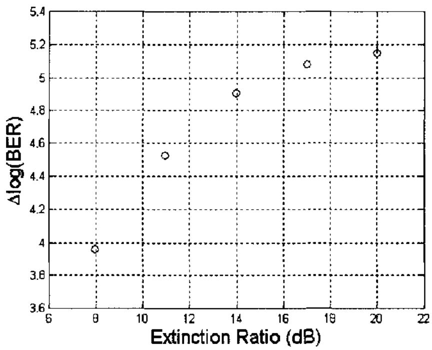

Fig. 1. $\Delta \log(BER)$ versus transmitter extinction ratio when the regenerator is located in its optimal position; $\sigma = 0.1$.

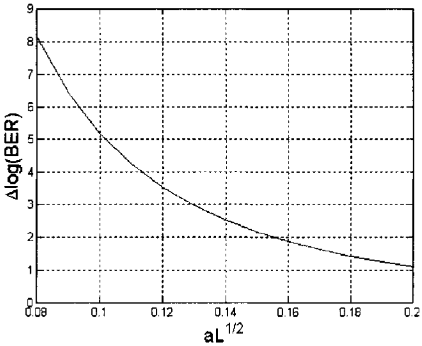

Fig. 2. Calculated $\Delta\log(BER)$ as a function of $a\sqrt{L}$ for $l/L = 0.5$ and an extinction ratio of 20dB.

Conclusions

In summary, we calculate the bit-error-rate (BER) improvement as a function of transmitter extinction ratio and the optical link noise parameter with a new method we proposed recently.

References

1 Geert Morthier et al IEEE Photon. Technol. Lett., vol. 12 (2000), pp.1516-1518
2 T. Otani et al IEEE Photon. Technol. Lett., vol. 12 (2000), pp.431- 433
3 Mingshan Zhao et al IEEE Photon. Technol. Lett., vol. 15 (2003), pp.305-307
4 Peter Öhlén et al IEEE Photon. Technol. Lett., vol. 9 (1997), pp.1011-1013
5 F.G. Sun et al IEEE Photon. Technol. Lett. Vol. 16 (2004), pp.1406-1408