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Contribution to the Study of 2R Regenerators in Optical Transmission Link into Account the PMD

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Abstract: With the development of optical communication systems in high bandwidth fiber, various degradations affect the propagation of light signals such as polarization mode dispersion which represents a temporal pulse broadening, it becomes troublesome from long and long distances for this, it is necessary to regenerate the signal optically, that is to say, the amplified (1R regeneration) , the reshaping (2R regeneration) and sometimes resynchronize to overcome the phenomenon of jitter time (3R regeneration). In this paper we study the contribution of 2R optical regenerator self-modulation to combat the phenomenon of polarization mode dispersion. The experiment is simulated with optisystem.

Key words: 2R optical regeneration, polarization mode dispersion, bit error rate.

1. Introduction

Optical regeneration [1], which allows amplification (1R Amplifying Repeater), the reshaping (2R) and data resynchronization (3R), is one of the functions for which research efforts are important. Many optical functions have been developed for increasingly powerful solutions at ever higher bit rates [2].

The versatility of the optical signal regeneration techniques they can mediate a broad spectrum of effects limiting the optical transmission systems scope. If regenerators are especially designed to combat the accumulation of amplified spontaneous emission noise, their behavior in the presence of polarization mode dispersion is little known [3].

We mean functions that simultaneously regenerate all wavelengths in the same device, as does the EDFA (Erbium Doped Fiber Amplifier) for amplification; or the integrated devices on a single chip so that each wavelength is treated separately with a size and low cost. Publications have shown the ability to integrate such devices [4]. This paper is organized as follows: Section 2 describes the polarization mode dispersion and 2R regeneration. In Section 3, the simulation is mentioned. Section 4 explains results and discussions. Finally the paper is concluded in Section 5.

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2. Polarization Mode Dispersion and Optical Regeneration

The PMD (polarization mode dispersion) is a phenomenon related to the light polarization [5-10]. It has the effect of temporally separated pulses in two orthogonal polarizations. The time difference group is called DGD (differential group delay). This effect does not take into account only the first frequency order; it is the PMD order 1. After quadratic detection pulses are broadened and interfere with each other [10-12]. The DGD is a random variable that follows a Maxwell. Its average value Δτ increases by the square root of the length and is expressed in picoseconds:

$$\Delta\tau = coef_{PMD}\sqrt{L} \quad (1)$$

The PMD effect becomes troublesome from a 10% T_b , the DGD of 10 ps is the tolerable limit for a 10 Gbit/s and the maximum distance (without signal regeneration) is limited to 400 km. A very high bit rate (> 40 Gbit/s), the all-optical regeneration appears as an attractive solution to combat PMD regeneration [13].

2R regeneration ensures the re-amplification of the signal and its fitness: its primary role is to reduce the amplitude jitter affecting the signal. But this technique is usually accompanied by the creation of an additional timing jitter [14].

There are three 2R regeneration modes: 2R regeneration self-phase modulation (SPM), 2R regeneration cross-phase modulation (XPM), and 2R regeneration four-wave mixing (FWM) [23-24]. In the following sections we are only interested in the first two types of regeneration.

"2R regeneration optical self-modulation" (Fig.1): the degraded signal controls the port and leaves regenerated. T is the transmission function of the nonlinear optical port:

$$T = P_{out}/P_{in} \quad (2)$$

With P_{in} and P_{out} are the powers of the input signal and the output of the regenerator. So this plan of operation is characterized by the equation:

$$P_{out} = P_{in}T(P_{in}) \quad (3)$$

The principle of 2R regenerator self modulation (SPM) is already explained in [15-18]. An all-optical 2R regenerator is implemented by SPM based spectral broadening and offset filtering is already explained in [22].

"2R regeneration cross-phase modulation" (Fig. 2), the degraded signal (the pump) always modulates the port transmission, but another signal is injected into the port (the probe) and sees the modulation transmission created by the degraded signal. The output signal of the port is modulated in the rhythm data. Most often, there is conversion of wavelength to the gradient of the second signal. $P_{probe,out}$ is the out probe power of the port.

This operating mode is described by the equation:

$$P_{probe,out} = P_{probe,in}T\ (P_{pump,in}) \quad (4)$$

In general, the cascade of 2R regenerators creates additional timing jitter which ultimately forms the boundary to the cascade of this type of optical function [19-20]. Provost et al. [21] have developed general design rules to optimize the many parameters

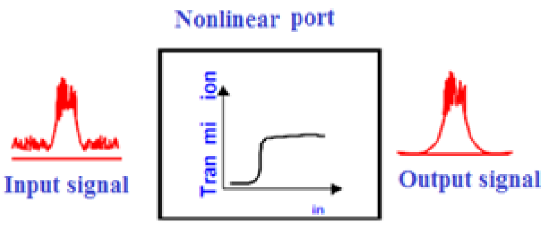


Fig. 1 Self-2R regeneration.

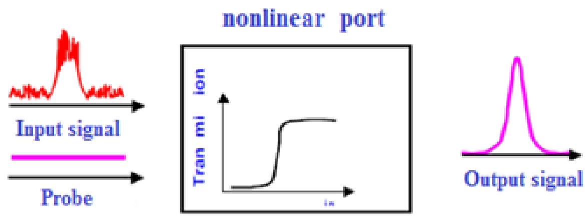


Fig. 2 Cross-2R regeneration.

of such a regenerator (non-linearity, dispersion and fiber length, width and offset filter) to get the best improvement in the rate of extinction signal.

3. Description of Simulation

In this simulation we study the contribution of 2R regeneration self-modulation to combat PMD.

It offers two simulation tests mentioned in Fig. 3.

The first: The 2R regenerator is placed directly in front receiver;

The second: The 2R regenerator is placed between two transmission lines.

In this simulation we use subsystems.

A subsystem is like a component, it has an icon, parameters, and input, output ports. A subsystem can be built using a components group or other subsystems [22]. It can easily be created by grouping selected components in the layout.

The simulated system is composed by the following subsystems:

(1) Transmitted subsystem;

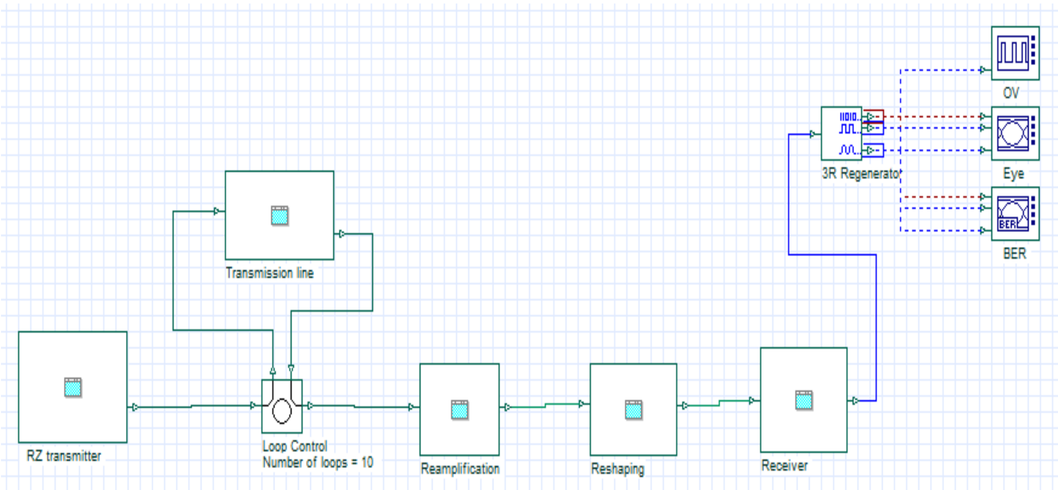
(2) Transmission line subsystem;

(3) 2R regenerator subsystem;

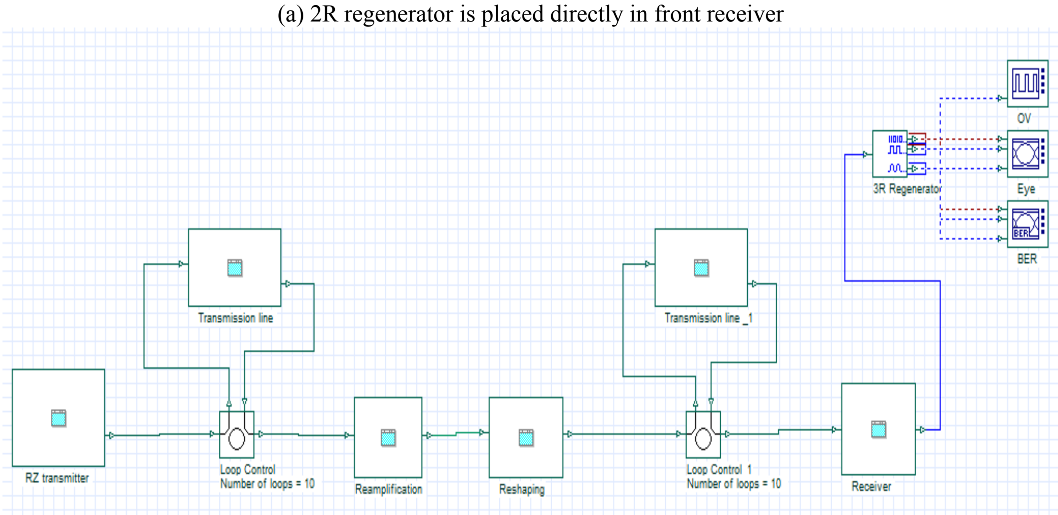
(4) And a receiver subsystem.

3.1 Transmitter Sybsystem

As shown in Fig. 4, the transmitter subsystem is



(a) 2R regenerator is placed directly in front receiver



(b) 2R regenerator is placed between two transmissions lines

Fig. 3 Simulation setup of the proposed system.

simply a signal RZ (return to zero) that is the bit rate D, it consists of a random binary sequence, NRZ modulator, an electrical sine waveform signal, a CW (continuous wave) optical signal and Lithium Niobate Mach-Zehnder modulator. The RZ signal is amplified and then filtered to obtain an optical signal of noise ratio equal to 35.7 dB (about 0.1 nm).

3.2 Transmission Line Subsystem

Fig. 5 is the transmission line in the system, in which it takes a SPAN that is to say a transmission fiber of length L = 100 km and a PMD coefficient = 0.5 $ps/\sqrt{km}$, an erbium doped fiber amplifier, and a dispersion compensating fiber of length L = 4 km and a PMD coefficient = 3.5 $ps/\sqrt{km}$.

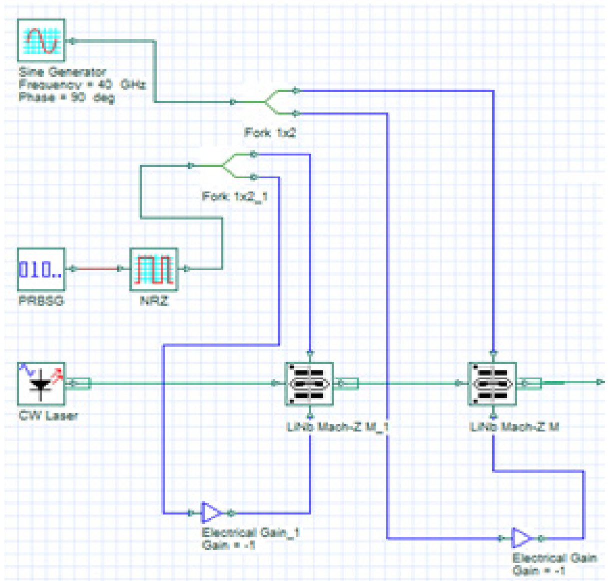


Fig. 4 Transmitter subsystem.

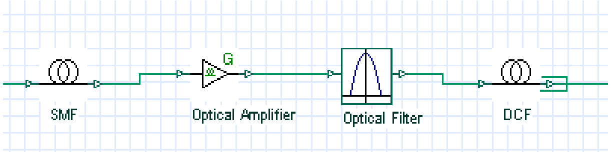


Fig. 5 Transmission line subsystem.

Do not forget an optical attenuator which keeps the input power fiber transmission constant after each round.

A recirculation loop, it is a new tool for evaluating a transmission line optically 2R regenerated.

The loop topology starts at the loop output port and terminates at the loop input port. The signal enters the input port and circulates in the loop N times, where N is defined by the parameter number of loops.

3.3 Subsystem 2R Regeneration (Re-amplification and Re-shape)

Fig. 6 is the regeneration subsystem such as the re-amplification is done through an amplifier EDFA while fitness is achieved through an optical gaussian filter order 1.

3.4 Receiver Subsystem

Fig. 7 represents the receiver subsystem. It consists of a PIN photodiode and a low-pass filter electrical (Bessel order 5) allows taking into account the bandwidth of the receiver.

The signal at the output of the electric filter is finally characterized by analyzing the bit error rate, the eye diagram, and an oscilloscope electric power analyzer.

4. Discussion of Results

In this section, we present the simulation results of the studied simulation tests.

Fig. 8 and Fig. 9 indicate that the contrast can be seen in transit due to the loss in the optical fiber and other optical devices can cause signal attenuation; as PMD will expand and deform the optical signal because the chromatic dispersion is compensated in link optical. The nonlinear effects are not taken into consideration .We note that the noise is extremely low (green curve).

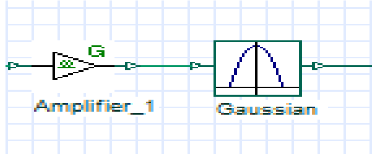


Fig. 6 Subsystem 2R regeneration.

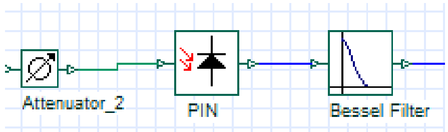


Fig. 7 Receiver subsystem.

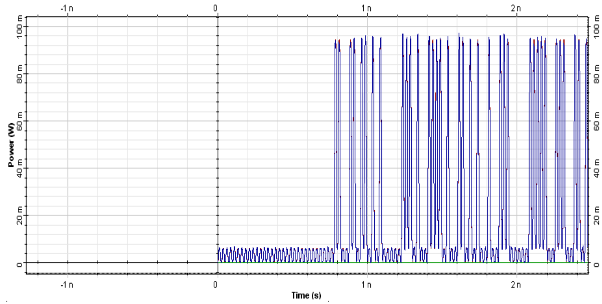


Fig. 8 RZ signal input.

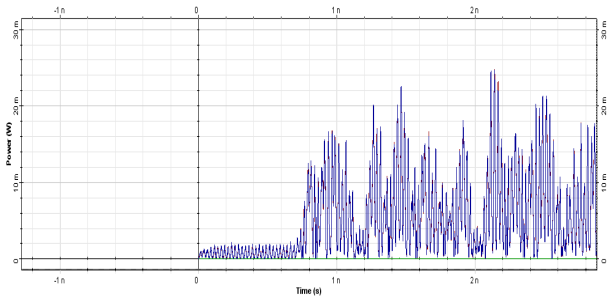


Fig. 9 Degradation data signal.

In the next section of simulation we study the performance criteria for measuring the transmission quality of an optical connection, taking into account the polarization mode dispersion.

These criteria are: eye diagram, quality factor, BER (bit error rate), OSNR (optical signal noise ratio) and penalty.

In the first step we are interested in the eye diagram which is a temporal representation of the signal sequence: this is temporally superimposed traces of the different accumulated a large number of bit time signal.

The results of this simulation are shown in Figs. 10-12.

Fig. 10 is the eye diagram without regeneration. We note that for a distance of 100 km a quality factor equal to 15.97 means that we obtain BER < 10^{-10}.

Fig. 11 and Fig. 12 represent the eye diagrams respectively recovered for 2R regeneration with a regenerator placed directly in the receiver front to another and placed between two transmission lines. We can clearly see the improvement of 2R regeneration in the eye diagram.

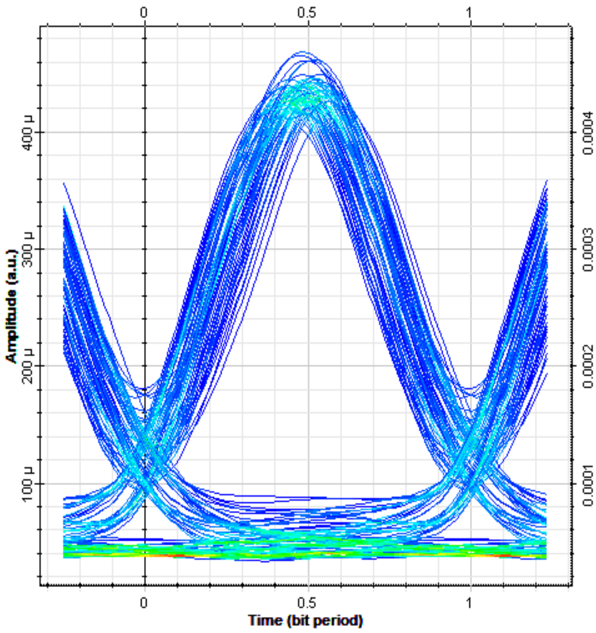


Fig. 10 Eye diagram for a signal without regeneration (Q = 15.97).

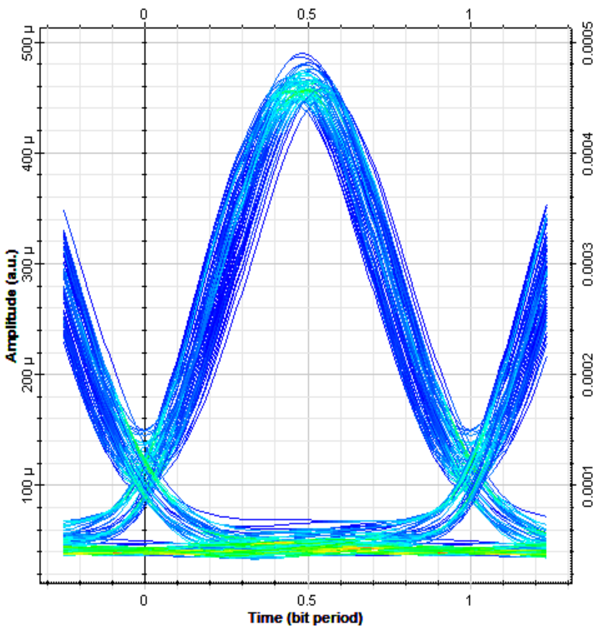


Fig. 11 Eye diagram for a regenerator placed directly in the receiver front (Q = 22.24).

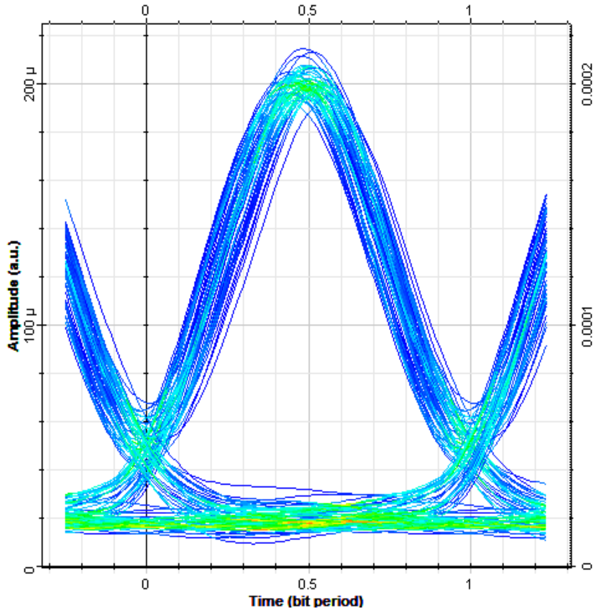


Fig. 12 Eye diagram for a 2R placed between two transmission lines (Q = 19.35).

The eye diagram after 2R regeneration is very open because the quality factor amplitude is respectively 22.24 and 19.35 for the two tests, the 2R regenerator has reduced the variance of the signal power of symbols probability densities transmitted in the second transmission fiber portion and that has improved the quality of the transmission.

These quality factors could lead us to believe that the transmission is very good.

We note that the results of the first test (Fig. 11) are good if you compare it with the second test (Fig. 12) because that one has an increased length (200 km instead of 100 km corresponding respectively to the DGD = 3.80 ps and 3.53 ps).

The only observation of the eye diagram does not pull conclusion as the regenerator quality.

The recirculation loop is the tool used to perform transmission long length (typically thousands of kilometers) from shorter lines (typically of the order of hundreds kilometers).

The principle is to circulate a “slice” signal, a number of times in the fiber in order to achieve the desired distance.

In the second step we have made measures BER and OSNR for different transmission length, that is to say for various revolutions of the recirculation loop to a regenerator placed in front receiver and another placed between two transmission lines. The results of this simulation are shown in Fig. 13 and Fig. 14.

From Fig .13, for a bit rate = 40 Gbit/s bond lengths do not exceed 1000 km for a 2R regenerator placed in directly front receiver for a while 2R regenerator placed between two transmission lines maximum length does not exceed 900 km because of increased delay between the states of polarization.

From Fig. 14, we see that the greater of the length the OSNR decreases. To maintain the quality of the transmission signal ($BER \leq 10^{-9}$) the optical signal noise ratio is respectively equal to 10.90 dB and 11.40 dB which corresponds to the length 1000 km and 900 km.

To assess the impact of the change, we use penalty parameter, it is defined as the difference (in dB) between the powers received on the receiver for a given BER (for example < 10^{-9}) before and after insertion of the function in the system (note that the power received at the receiver for a BER of 10^{-9} is called receiver sensibility). Measuring the penalty evaluates the added noise and distortion of the signal introduced by the device.

Fig. 15 represents the variation of BER as a function of the receiver power to a line containing only the transmitted and reception (btb without regeneration) it is simply without regeneration and for the same line in which the regenerator is inserted (btb with generator). We were able to determine the penalty for our optical function for PMD coefficient = $3.53\ ps/\sqrt{km}$ which proved to below.

From Fig .15,it is show that a penalty of 0.5 dBm of $BER = 10^{-9}$ for a bit rate = 40 Gbit/s.

A positive penalty means improving the opening of the eye diagram with respect to the reference aperture when the regenerator improves receiver sensibility.

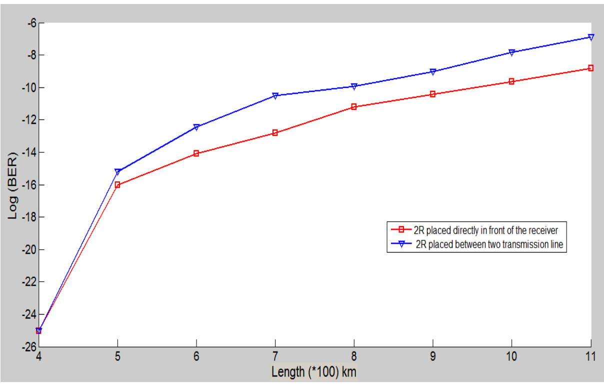


Fig. 13 Variation of the BER depending on the length (recirculation loop number).

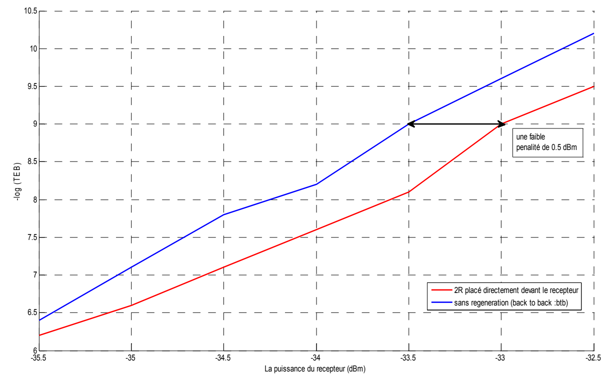


Fig 15 Evolution of the BER depending on the power of the receiver.

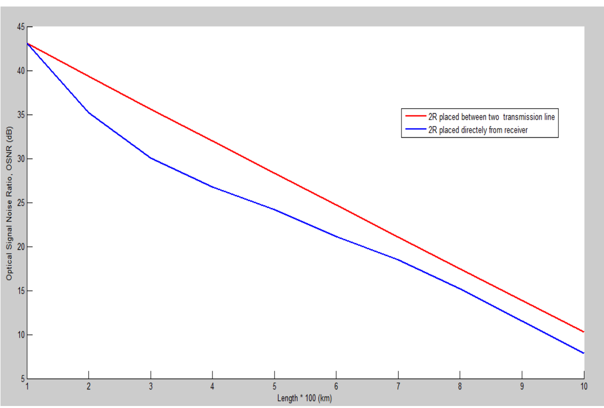


Fig 14 Variation of OSNR according to the length.

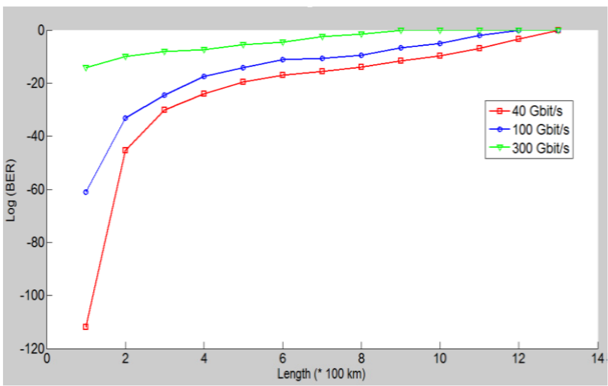


Fig 16 Variation of the BER as a function of length for different values of bit rate.

In the following section we study the influence of the length on the bit error rate but for different bit rate values (D1 = 40 Gbit/s, D2 = 100 Gbit/s, and D3 =300 Gbit/s).

The results of this simulation are shown in Fig. 16 for a regenerator placed directly from receiver.

From Fig. 16, it is noted that the higher bit rate increases, the BER also increases, as can be seen for a rate of 40 Gbit /s is the distance up to 1000 km, whereas a bit rate of 100 Gbit/s to 800 km and for 300 Gbit/s to 200 km which gives a BER $\leq 10^{-9}$, these results in the reduction of time between pulses, which make them more likely to inter-symbol interference.

It is noted that the bit rate does not affect the DGD but affects the quality of transmission; we see that the DGD in an optical fiber (SMF or DCF) varies randomly with the length wave and also the environmental conditions in which the fiber is located. This is due to random methods of coupling and deformation of the heart due to external stresses on the fiber.

The polarization mode dispersion induced broadening of the pulses propagates in the fiber as well as a limitation to the transmission performance. PMD has a significant impact on system performance when DGD exceed -30% of the bit period.

The Fig. 17 represents the penalty variation according to the DGD.

From Fig. 17, we note that the higher the DGD increases the penalty increases as it means that the performance of the system studied is reduced. The curves with and without regenerative meet for a DGD = 10.21 ps below this value, the regenerator can significantly reduce the penalties.

More than DGD, there are other parameters such as the degree of polarization. The parameter is a very important character for the PMD; the latter is related to power exactly.

Placing a polarization controller at the output of the fiber, this later sets the input signal in an arbitrary polarization state and is placed at the fiber output. The azimuth and ellipticity parameters define the polarization state of the output signal. In this case, the output polarization is independent of the input signal polarization. This polarization controller allows the degree of polarization does not change (remains unchanged) and equal to 100%, this means the PMD is canceled in the transmission chain.

In three stages, increases the number of transmission spans simulated in link and also the 2R regenerator's number. Fig. 18 is the variation of the quality factor as a function of SPAN number (regenerator number).

According to Fig. 18, when the number of SPANs increases the quality factor decreases due to the increased distance therefore the PMD coefficient also increases. To maintain good quality of transmission requires that the tolerable DGD should not exceed a 4 ps for a distance approximately of 60 SPANs that is to say 6000 km for a bit rate of 40 Gbit/s.

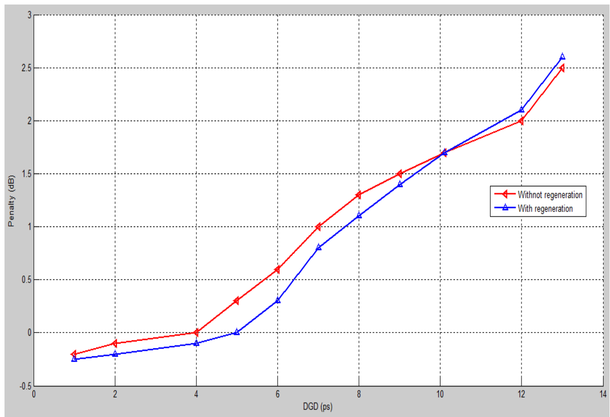


Fig 17 Variation of penalty according to DGD with and without regeneration.

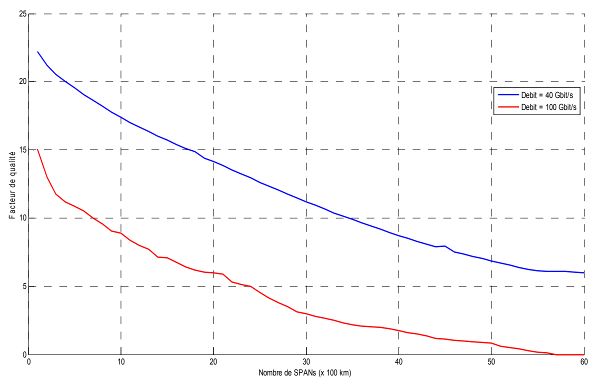


Fig 18 Quality factor based on the SPANs number (regenerator number).

5. Conclusion

2R regenerators can be classified into two categories: regenerative self-modulation and cross modulation regenerators.

Our results show that the 2R regenerator self-modulation is a technique used to combat PMD in a transmission link by optical fiber, and that we observe in improving eye diagram, the BER and minimize the maximum variation of degree of polarization when PMD coefficient increases, that is the DGD. The Polarization controller allows the degree of polarization does not change and equal to 100%, this means the PMD is canceled in the transmission chain.

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