Simulation study and analysis in transmitting RZ and NRZ coded signals into 10 Gbps optical line with optical amplifying sections

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The topic is associated with linear coding and modulation in optical transmission channels in terms of ensuring maximum distance transmission, high Q-factor, lower BER, good spectral characteristics and energy budget of the system, considering the main limiting factors transitional characteristics and limitations of the dispersion and the fiber attenuation, nonlinear effects and the number of amplifying sections. In the publication are presented and compared simulation results of realized model in transmitting RZ and NRZ coded signals in 10Gbps optical line with optical amplifying sections, using the software - OptiSystem with length of the optical fiber line 100 km and 200 km. The signals are distributed via a single mode optical fiber (SMF) and with optical amplification, considering the dispersion of the group distribution speed, self-phase modulation (SPM), line losses and periodic amplification by adding the noise of increased amplified spontaneous emission (ASE).

Симулационно изследване и анализ при предаване на RZ и NRZ кодирани сигнали в 10 Gbps оптична линия с оптични усилвателни участъци (Станимир Садинов). *Темата е свързана с линейното кодиране и модулация в оптични канали за пренос от гледна точка на осигуряването на максимална дистанция на предаване, висок Q-фактор, респективно по-ниска стойност на BER, добри спектрални характеристики и енергиен бюджет на системата, отчитайки основните ограничаващи фактори преходните характеристики и ограниченията от дисперсията и затихването по влакното, нелинейните ефекти и броя усилвателни участъци. В публикацията са представени и сравнени симулационни резултати от реализиран модел при предаване на RZ и NRZ кодирани сигнали в 10Gbps оптична линия с оптични усилвателни участъци, като е използван програмен продукт OptiSystem при дължина на оптичната линия 100 km и 200 km. Сигналите се разпространяват по едномодово оптично влакно (SMF) и с оптично усилване, като се вземат под внимание дисперсията от груповата скорост на разпространение, фазовата самомодулация (SPM), линейните загуби и периодичното усилване с добавяне на шумът от усилено спонтанно излъчване (ASE).*

Introduction

Present day application of optical communication lines varies from corporate networks to inter-continental communication lines. A number of advantages that are inherent to fiber optic elements and equipment have allowed their use on such massive scale. By means of proper transceiver modules signals can be transferred in their original shape with no need of frequency conversion or digitalization for the transmission section of the system [2], [3], [5], [6], [7]. Along with the development of optical communications, there comes the issue of how to achieve greater high-speed action, steady and stable operation of devices [1]. This necessitates extensive use of digital signals and the respective systems for their processing. Digitalization replaces the infinite quantity of symbols that are received from a certain source with a finite set of symbols – binary code [3], [5], [6]. Thus in the process of signal transmission it is necessary that they be presented as different binary codes or received from other similar ones.

In optical communications the terms RZ (Return to Zero) and NRZ (Non - Return to Zero) are used in a different way. Since there is no negative light, NRZ will mean that a bit with logical value of "1" (one optical pulse) changes its value (from light to a lack of light or vice versa) within the limits of the period of bits. On the other hand, RZ indicates that the optical pulse is narrower than the period of bits.

This publication presents the implementation of a simulation model of optical transmission line with carrying capacity of 10 Gbps along single-mode optical fiber and optical amplification using RZ and NRZ coding. Simulation and modeling have been done with OptiSystem software, a product of Optiwave [4].

The simulation model aims at optimizing input optical power and length of DCF fiber that will ensure maximum Q-factor (respectively minimum BER) in the receiver.

Implementation of simulation model of transmitting RZ and NRZ coded signals in 10Gbps optical line with optical amplified sections

For the purpose there are developed two simulation models, which are graphically represented on:

- Fig. 1 – optical transmission line with RZ-coded signal;
- Fig. 2 – optical transmission line with NRZ-coded signal.

The basic parameters of the model are as follows:

- Bit transfer rate: 10Gbps;
- Binary sequence length: 128 bits;
- Number of samples per bit: 128.

There is no difference between both models (with RZ and with NRZ coding) in the PRBS generator binary sequence settings:

- Pulse shape: Gaussian;
- Pulse ratio: 0,5 bit;
- Time for pulse front growth: 0,15 bit;
- Falling edge time: 0,25 bit.

External modulation laser (block CW Laser) with carrier frequency λ = 1550 nm and frequency band of 0,1 MHz is used as an optical source .

The length of each amplifying section is set in the Optical Fiber Block:

- optical fiber length: 25 km;
- dispersion coefficient : D = 17 ps/(nm.km);
- dispersion slope: $\partial D/\partial\lambda$= 0,08 ps/(nm^2.km);
- Nonlinearity coefficient: γ = 1,31 (1/(km.W));
- kilometer attenuation of fiber: α = 0,2 dB/km.

Loop Control Block (on figures 1 and 2), simulates the amplifying sections of optical transmission line. Therefore the total optical line length will be determined by the number of amplified sections multiplied by their length (25 km):

- For Fig. 1 – 8 sections x 25 km = 200 km;
- For Fig. 2 – 4 sections x 25 km = 100 km.

The EDFA Amplifier Block in each section is with the following settings:

- Amplification coefficient: 5 dB;
- Amplifier noise number: 6 dB;
- Noise frequency band: 13 THz;
- Dispersion: 16 ps/(nm.km);
- Dispersion slope: 0,08 ps/(nm^2.km);
- Differential group delay time: 0,2 ps/km;
- PMD coefficient: 0,5 ps/km.

Properties of Bessel band-pass optical filter (block Bessel Optical Filter) are:

- Wavelength: 1550 nm;
- Frequency bandwidth: 4 x Bit rate.

Properties of Low Pass Bessel Filter:

- Cut-off frequency: 0,75 x Bit rate;
- Maximum attenuation: 100 dB;
- Filter order: 4.

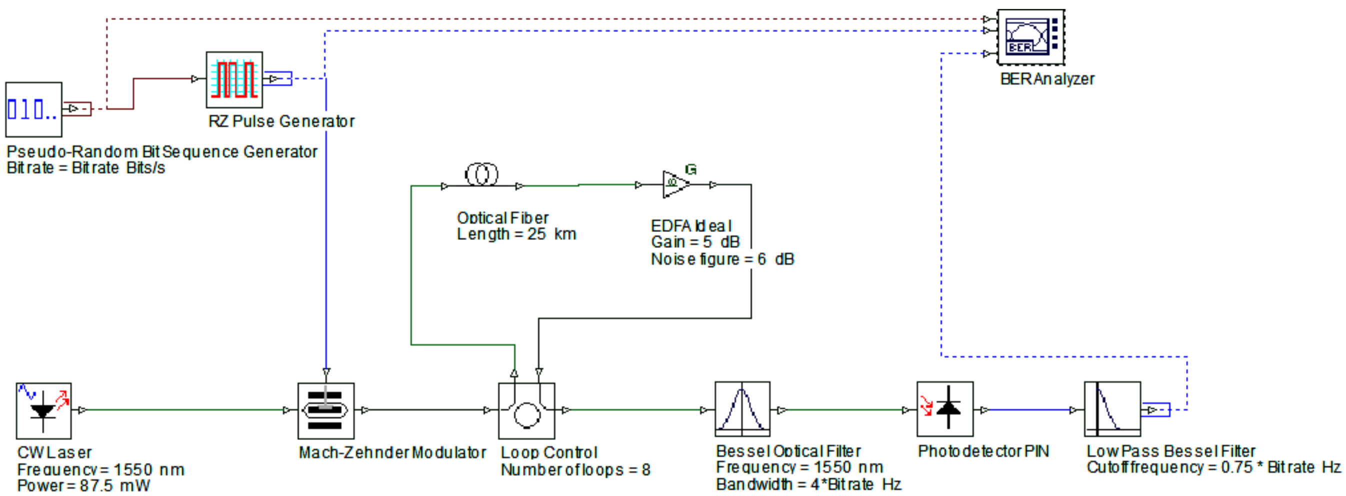


Fig.1. Model of 10 Gbps optical transmission line with amplifier and RZ coding of signal.

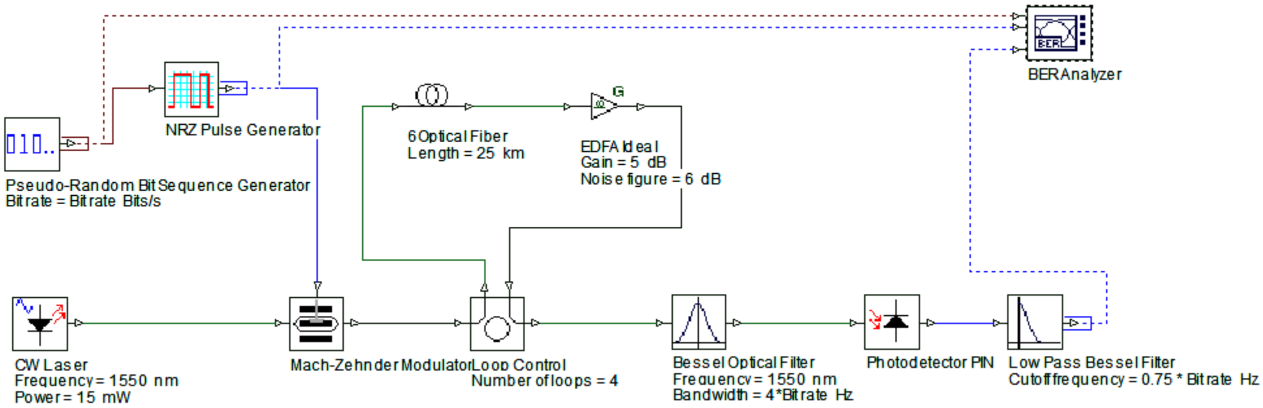


Fig 2. Model of 10 Gbps optical transmission line and NRZ coding of signal.

Study and analysis of transmitting RZ and NRZ coded signals in 10Gbps optical line with optical amplification sections

Based on the studied model for transmission of RZ and NRZ coded signals in 10Gbps optical line, here are presented the results from different simulations, comparisons and analyses.

The results in transmission of RZ coded signals are shown on Fig. 3 and the results for NRZ coded signals – on Fig. 4.

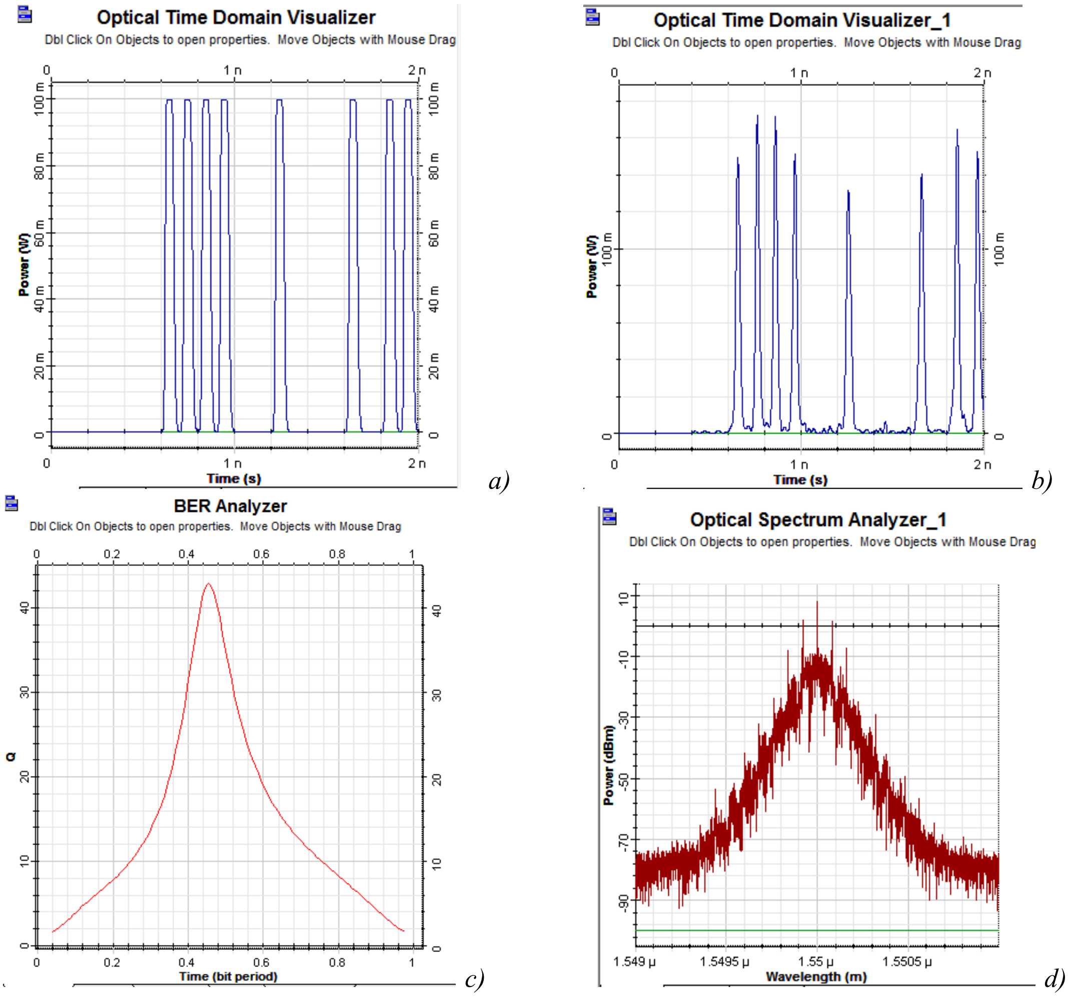


Fig.3. Transmission of RZ coded optical signals along 10 Gbps optical line with length of 100 km: a) Time diagram of transmitted optical signal, b) Time diagram of received optical signal, c) Q-factor and d) optical spectrum.

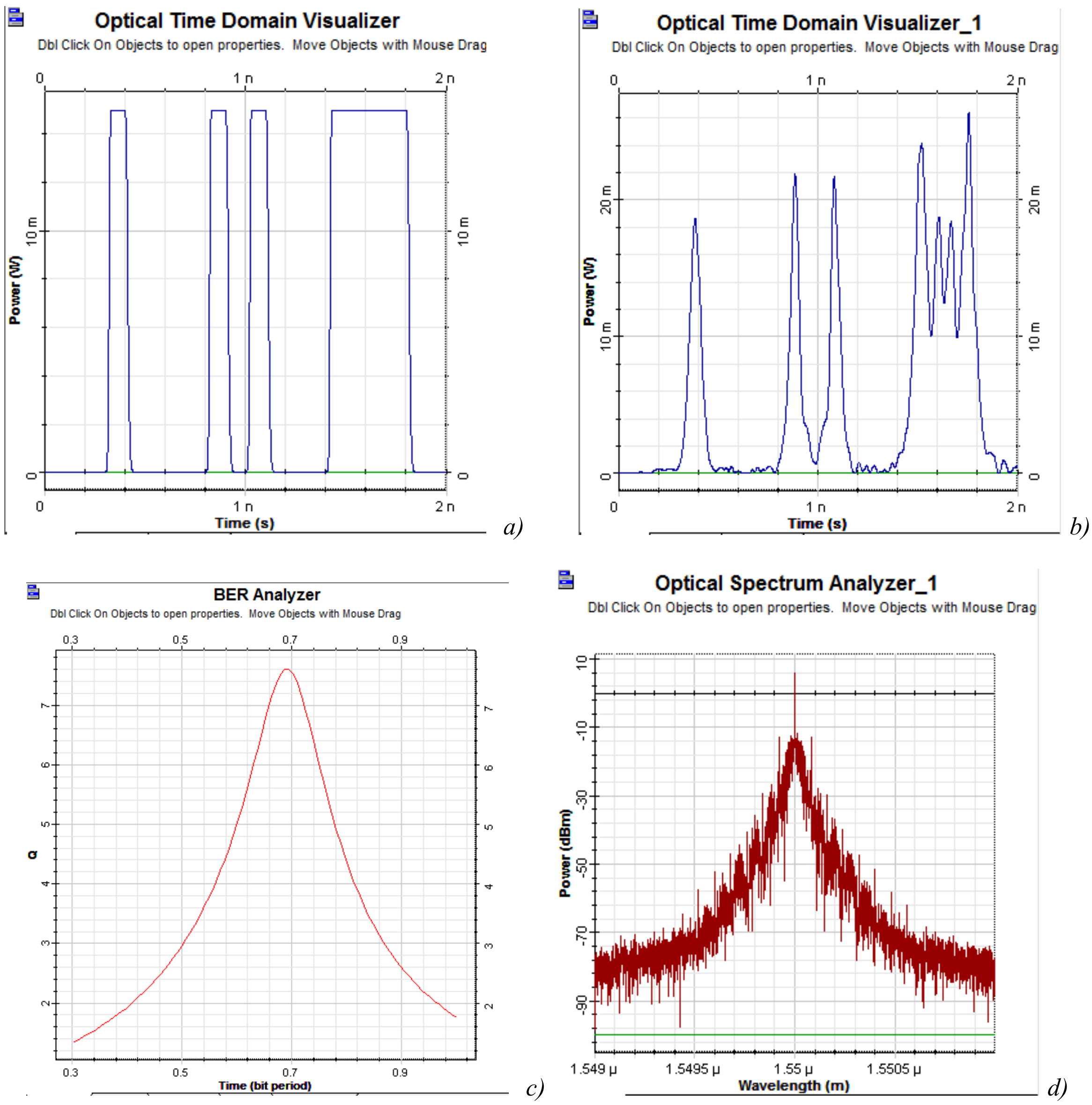


Fig.4. Transmission of NRZ coded optical signals along 10 Gbpsoptical line with length of 100 km: a) time diagram of transmitted optical signal ,(b) time diagram of received optical signal, (c) Q-factor and, (d) optical spectrum.

Comparative analysis

All results obtained from simulation and presented in here are related by way of comparing their behavior in the system during transmission of RZ and of NRZ coded signals. The comparison is made under the following conditions:

- Concerning the case of RZ coding, the pulse ratio is equal to 0,5, whereas the optical source power is 87,5 mW;
- Optical source power is 15mW in the case of NRZ coding.

Fig. 5 presents the eye patterns for optical signals, modulated by two ways of coding for 100 km optical line length (4 amplification sections) at 10 Gbps transmission rate along single-mode optical fiber.

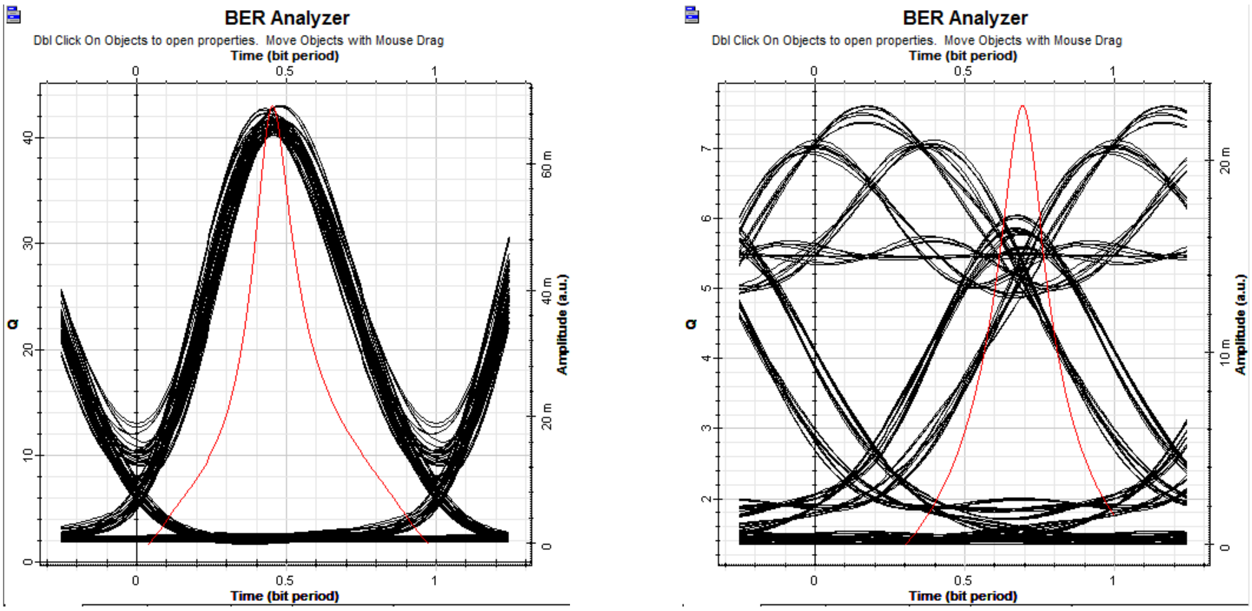
Fig. 6 presents eye patterns for optical signals, modulated by two ways of coding for 200 km optical line length (8 amplification sections) at 10 Gbps transmission rate along single mode optical fiber.

When comparing figures 5 and 6 it is evident that in the case of doubled number of amplification sections:

- Q-factor in RZ-coding of optical signals deteriorates from 42,9 with 100 km length (errorless transmission of optical signals, i.e. optimal case) to 6,8 with 200 km optical line length (BER = $3{,}22.10^{-12}$ - approximately equal;
- Q-factor in NRZ-coding of optical signals is 7,8 with line length of 100 km (BER = $1{,}41.10^{-14}$ – lower than the maximum permissible value),

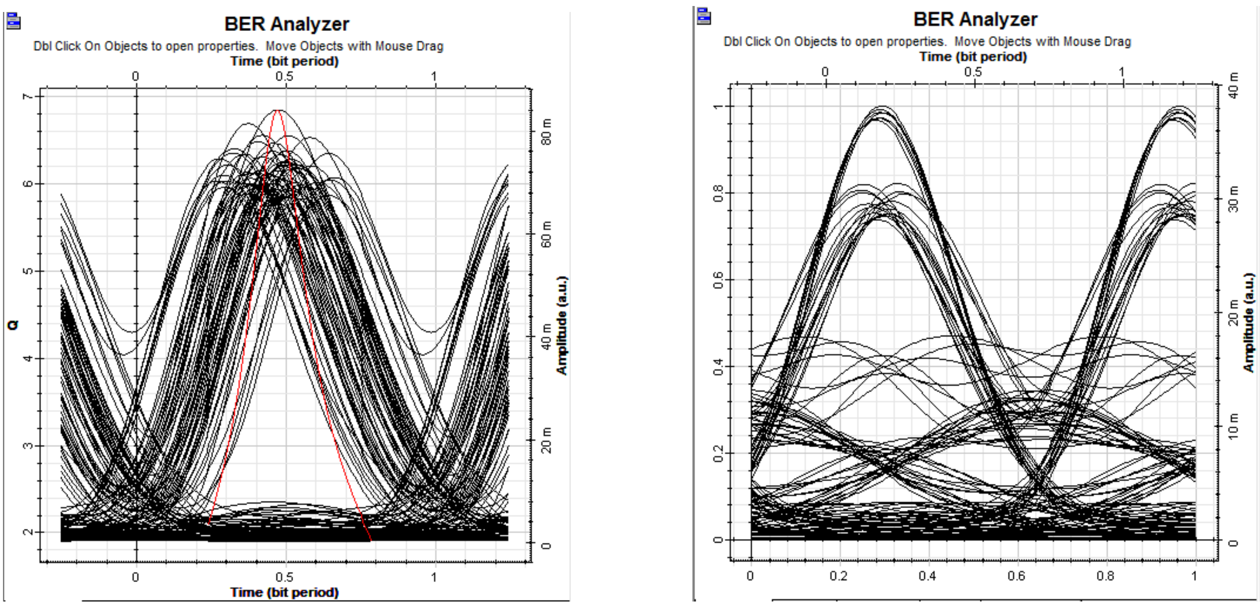
whereas with line length of 200 km nonlinear effects and attenuation cause quite a lot of errors in the authorization unit making communication impossible.

In addition to the presentation of results it is worth to mention that the selected optical source power during RZ coding is 87,5 mW whereas with NRZ coding the selected power is 15 mW, which is based on power optimization aiming at maximum Q-factor. For all other values of power there will be obtained a poorer Q-factor due to the great impact of attenuation at low input power and also because of the great impact of nonlinearities at higher input power.



a) b)

Fig.5. Eye patterns of received optical signals for 10 Gbps optical line with length of 100 km during (a) RZ coding and (b) NRZ coding.



a) b)

Fig.6. Eye patterns of received optical signals for 10 Gbps in optical line of 200 km of length during (a) RZ coding and (b) NRZ coding.

Conclusion

With optical line lengths of 200 km and over and concerning the instance of RZ coding, the maximum Q-factor becomes less than its minimum permissible value, i.e less than 6. This implies that BER deteriorates intensively which is why this appears to be the maximum distance with good value for Q-factor. In the instance of NRZ coding it is evident a minimum permissible Q-factor is obtained with line lengths of up to 100 km.

By comparing both cases of modulation with RZ and NRZ coded signals it becomes evident that RZ coding presents a better option since it ensures operation at much higher input power and with almost two times longer optical lines.

Based on the simulated studies of models it is possible to draw the following major conclusions:

- The optical receiver in the optical communication channel is characterized by a certain sensitivity threshold, which in turn assures minimum value of BER. When the level of received optical power is below that threshold value, the aperture of the eye pattern is minimal, in other words, the authorizing device cannot make the right decision, which will result in lower BER (too many errors). In practice, this means that there will be no communication.
- Provision of higher input power will not necessarily ensure better results. With too high levels of the power received by the optical receiver, the photodetector may become saturated which in turn may lead to restriction mode, nonlinear deviations and deterioration of BER. This problem can be solved by inclusion of optical attenuator at the optical receiver input and by tuning received optical power within the required limits.
- Obtained results also prove that RZ coded signals provide better basic sensitivity of the receiver when the average power within the fiber is sustained at a constant level.
- RZ coded signals are affected to a greater extent by dispersion and dispersion slope. For 10-20-Gbps-systems, in which dispersion and its slope are well compensated in most of the cases RZ coded signals perform better than NRZ signals. An exception is the mode of zero dispersion inside the fibers with zero dispersion offset wherein nonlinear effects will dominate. Since 40-Gbps-systems are restricted by both dispersion and dispersion slope, NRZ could be a better option for a system with a large number of channels.
- The application of RZ circuit for modulation requires higher speed driver in the receiver. This circuit could also be affected by means of two optical modulators, which is a more costly solution. Inside the receiver, the optimum frequency band of the filter for RZ coding could be the same as that of NRZ coding.

It is possible, by means of presented simulation models, to solve optimization tasks that aim to determine optical power insert plus the length of the dispersion compensation fiber, the governing criterion being maximum Q-factor and accomplishment of some expected value of BER. Proposed approaches can be applied in new interactive and electronic forms of distant and web-based learning.

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