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COMPUTER MODELLING AND ANALYSIS OF DISPERSION COMPENSATION SCHEMES IN OPTICAL COMMUNICATION LINES

Krasen Angelov [1], Stanimir Sadinov [2], Panagiotis Kogias [3]
[1, 2] Technical University of Gabrovo, Bulgaria
[3] Technological Educational Institute of Eastern Macedonia and Thrace, Greece

Abstract
In this paper, it is simulated 40Gbps high-speed single channel transmission in optical communication line using different dispersion compensation schemes (pre-compensation and post-compensation). System is analysed by searching the optimum input power for different bandwidth of the line. The system is analysed and evaluated in terms of BER, Q factor, eye opening factor and optical signal spectrum.

Keywords: Optical link length, Optical dispersion, Linear and nonlinear distortions, Optical power level.

ВЪВЕДЕНИЕ

Data transmission rate in an optical communication line actually is limited value. In an optical communications network over long distances or high data rates, it can be influenced and limited by a number of factors: by losses (attenuation-limited transmission) or the dispersion of the fiber (dispersion-limited transmission). [1,5,8]. In this case, the determination of maximum length of the optical line will depend on different technical aspects: what type of source is selected; how the energy budget is limited; what is the performance of the equipment (i.e. timing analysis); what is the transmission length, limited by either dispersion or attenuation.

In optical communication link, the parameters of the medium are dependent on wavelength of the optical signals spreading through the medium. This results in degradation of the optical signal along the optical fibers, because the different group velocity and varying delay at the receiver input "smears out" the signal in time. [1,8].

This paper presents the implementation of a simulation model of 40 Gbps single channel optical transmission line along single-mode optical fiber and optical amplification. The simulation model aims at study and comparative analysis of RZ- and NRZ-modulation format transmission analyzing the following major factors: how the medium will affect the duration of an optical pulse traveling through it (i.e. GVD – group velocity dispersion), the nonlinear effects such as SPM (self-phase modulation), the linear losses, and the number of amplifying sections with amplified spontaneous emission (ASE) noise. The large GVD could be compensated by using either a post-compensation or a pre-compensation scheme.

The simulation models proposed in this paper are used to investigate and solve optimization tasks – complex searching for optimal conditions in terms of ensuring maximum distance transmission [5], high Q-factor [4], lower BER, good spectral characteristics and energy budget of the system [3,6], considering the main limiting factors, transitional characteristics and limitations of the dispersion and the fiber attenuation, nonlinear effects, the number of amplifying sections [7], inserted noise influence [2] and dispersion compensation schemes.

IMPLEMENTATION OF SIMULATION MODEL OF 40 GBPS SINGLE CHANNEL OPTICAL TRANSMISSION LINE

For the purpose, there are developed two simulation models, first of which is

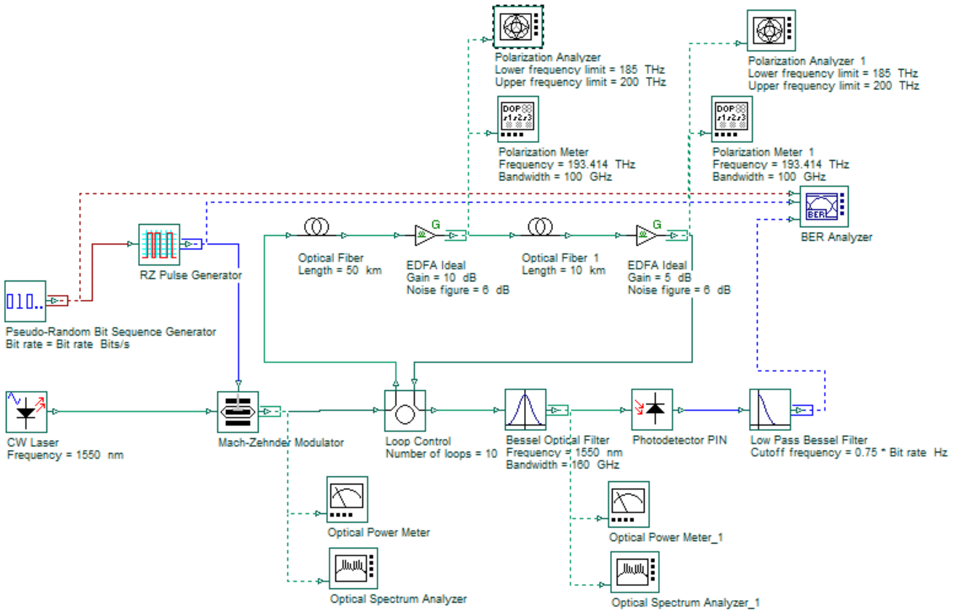


***Fig. 1**. Simulation model of 40 Gbps single channel optical transmission line with RZ-modulation format and dispersion post-compensation scheme*

represented on Fig. 1 – 40 Gbps single channel optical transmission line over single mode fiber with RZ-modulation format and post-dispersion compensation scheme.

For the second model with NRZ-modulation format, the RZ pulse generator block from Fig. 1 should be replaced with NRZ pulse generator block [5].

The fundamental limitation to high-speed communication systems over the embedded standard single-mode fiber (SMF) at 1550 nm is the linear chromatic dispersion.

The system supported data rate can be calculated as [5]:

$$B_R \leq \frac{0,7}{\Delta t_{sys}} \text{ - for NRZ-modulation format;} \quad (1)$$

$$B_R \leq \frac{0,35}{\Delta t_{sys}} \text{ - for RZ-modulation format;} \quad (2)$$

where Δt_{sys} is the rise time of a fiber-optic system - a parameter that shows how the circuit or system can respond to fast input signals [1,5,8].

Typical value of the group velocity dispersion β_2 = -20 ps^2/km at 1550 nm will leads to dispersion of 16 ps/(nm.km). For 40 Gbps bit rate and assuming a 50% duty cycle, the corresponding dispersion length will be approximately $L_D \approx 2,8$ km.

The basic parameters of the model are as follows: 40 Gbps bit rare, 3,2 ns time window will be, 0,195 ps sampling interval and 5,12 THz sample rate.

The used pseudo-random bit sequence generators are connected in the same way for both simulation models (with RZ- and NRZ-modulation). The RZ-generator is set to use a rectangle (Gaussian) shape with 50% duty cycle, 0,15 bit rise time and 0,25 bit fall time.

The optical source is modeled with externally modulated CW laser at 1550 nm carrier wavelength and 0,1 MHz line width.

In each amplifying section is used standard single mode optical fiber. It has the following parameters: 17 ps/(nm.km) dispersion coefficient, 1,31 (km.W)$^{-1}$ nonlinear coefficient, 0,2dB/km linear losses, and 50 km fiber length. After each segment from standard single mode fiber, an amplifier is used (to compensate the linear losses) with parameters of 10 dB gain and 6 dB noise figure. The dispersion compensation fiber (DCF) is with the following parameters: –80 ps/(nm.km) dispersion coefficient, 5,24 (km.W)$^{-1}$ nonlinear coefficient, 0,5dB/km linear losses, and 10 km fiber length. It is applied the post-compensation scheme to compensate the fiber dispersion. An amplifier compensates the linear losses after each segment from DCF.

RESULTS

The graphical dependencies of BER versus optical transmitted power (P_{TX}) are shown on Fig. 2 (for RZ-modulation format) and Fig. 3 (for NRZ-modulation format).

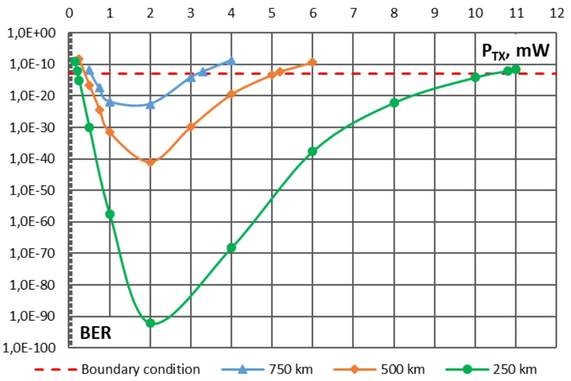


Fig. 2. *BER = f(PTX) for RZ-modulation format*

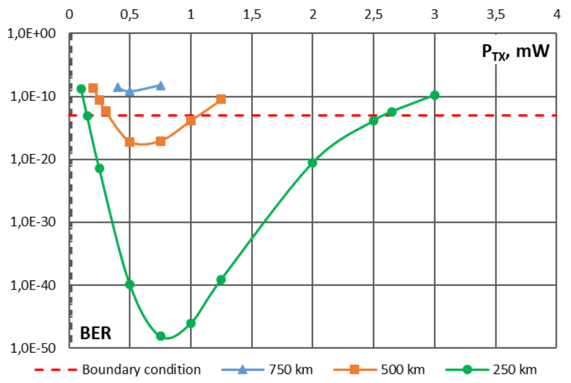
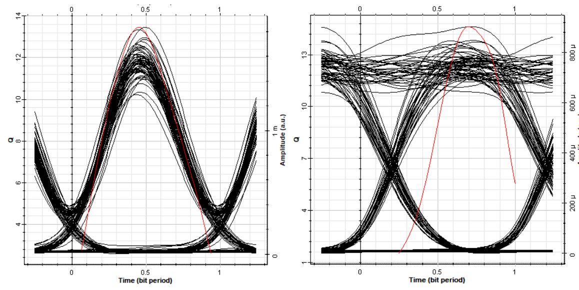


Fig. 3. *BER = f(PTX) for NRZ-modulation format*

Fig. 2 and Fig. 3 show results for optical line lengths of 250, 500 and 750 km (5, 10 and 15 amplifying sections x 50 km, respectively).

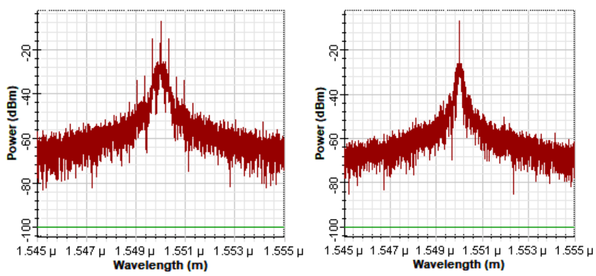
From the graphs in Fig. 2 it is evident that the optimum link length under considered conditions will be 500 km (10 amplifying sections x 50 km with periodical amplification in each section) when RZ-modulation format is used. The optimal point in which the BER value is the lowest is obtained for optical input power about 2 mW (3 dBm). On Fig. 4a is shown the corresponding eye-diagram and Q-factor of the optical signal. If the distance is greater than 750 km, BER value will be worse than the accepted value 1.10^{-13} (maximum Q-factor will be smaller than 6).

Fig. 3 shows the corresponding results for the case when NRZ-modulation format is used – the optimum link length will be 250 km (5 amplifying sections x 50 km with periodical amplification in each section). For this case the optimal point with the lowest BER value is obtained for optical input power about 0,75 mW (–1,25 dBm). If the distance is greater than 500 km, BER value will be worse than the accepted value 1.10^{-13} (maximum Q-factor will be smaller than 6). On Fig. 4b is shown the corresponding eye-diagram and Q-factor of the optical signal.



a) *b)*

Fig. 4. *Eye patterns of received optical signals for 40 Gbps optical line with (a) RZ- and (b) NRZ-modulation format*



a) *b)*

Fig. 5. *Optical spectrum diagram of received optical signals for 40 Gbps optical line with (a) RZ- and (b) NRZ-modulation format*

As can be seen from the spectral characteristics shown in Fig. 5, the RZ-modulated signals are affected to a greater extent by dispersion and dispersion slope, as well as by self-phase modulation. 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 especially for spectral multiplexed systems.

The simulation model shown on Fig. 1 is implemented using dispersion post-compensation scheme. Another known method is the use of dispersion pre-compensation scheme, as it is shown on Fig. 6 (for RZ-modulation format). Using this simulation model, the influence of two dispersion compensation schemes: post- and pre-compensation is studied and analyzed.

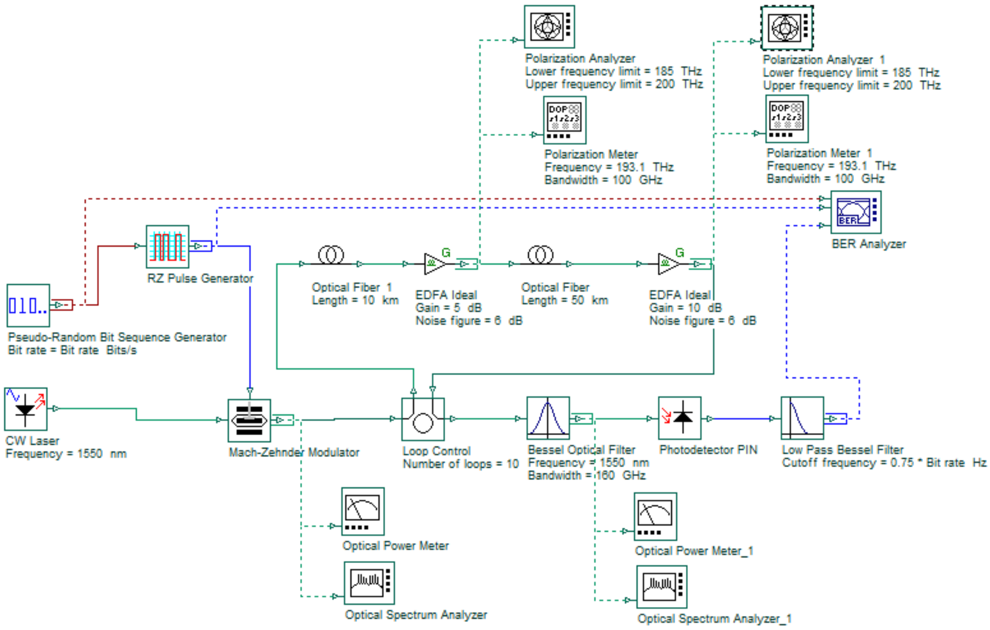


Fig. 6. *Simulation model of 40 Gbps single channel optical transmission line with RZ-modulation format and dispersion pre-compensation scheme*

On Fig. 7 are shown the corresponding comparative analysis results for the RZ-modulation transmission at 40 Gbps for both dispersion compensation schemes, and on Fig. 8 – for the NRZ-modulation transmission. Both figures shows the dependence of the maximum Q factor from the input optical power (P_{TX}).

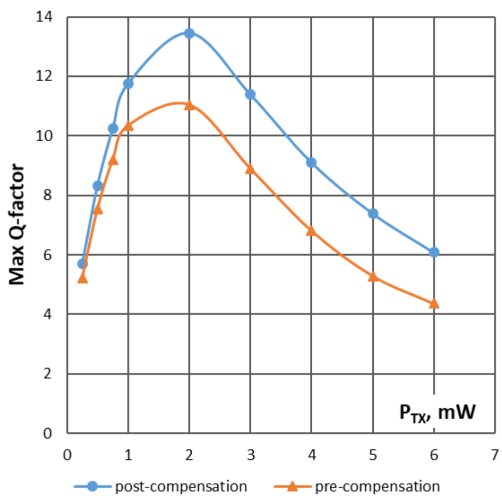


Fig. 7. *Max Q = f(PTX) for RZ-modulation format*

Both results show that the use of post-compensation scheme is more effective than the use of pre-compensation scheme to compensate the fiber dispersion at 40 Gbps single channel transmission system.

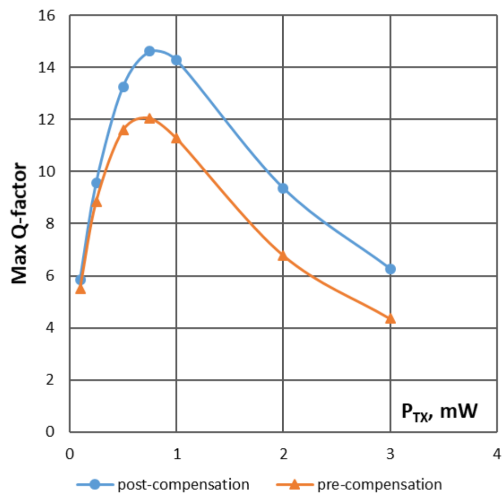


Fig. 8*. Max Q = f(PTX) for NRZ-modulation format*

CONCLUSION

Based on the simulated studies of models it is possible to draw the following major conclusions: Comparing the results obtained for the two Q-factors (respectively, the minimums of the BER values) it can be clearly seen that the input optical power is 1,25 mW greater when using RZ-modulation format. This results in a greater transmission distance with good Q-factor and BER performance. However, the RZ modulation format is only recommended for single channel systems due to the strong influence caused by dispersion and self-phase modulation.

At low power levels, the performance of the optical channel is greatly reduced due to the cumulative effect of the inserted amplifier noise. The self-phase modulation causes a significant reduction in the transmission distance at high input optical power levels. The obtained results lead to the conclusion that the post-compensation scheme provides better performance compared to the pre-compensation scheme in high-speed single channel transmission in optical communication line.

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