

USING MATLAB TOOLS FOR SIMULATION OF THE OPTICAL TRANSMISSION MEDIUM

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Abstract

The paper presents a design and simulation of the optical path which include linear and nonlinear effects using the MATLAB simulation tools. The program includes a calculation part of nonlinear effects and a simulation part where the signal is examined in a real time. This program deals with different types of modulation techniques and with characteristics of the optical environment.

1 Effects in the Optical Transmission Medium

Nowadays, an interest in the signal information transmission through optical fibers rapidly increased due to quality of transmission and broad bandwidth. This contribution covers modulation techniques utilized in the optical transmission medium. The paper will be focused briefly on negative influences of the optical environment. We will introduce simulation program which simulate chosen modulation techniques through optical transmission path.

Each optical fiber represents a transmission system, which is a frequency dependent. A pulse propagation inside this transmission system can be described by the nonlinear Schrödinger equation (NLSE) and this NLSE is derivate from Maxwell equations. From the equation we can obtain effects in optical fibers and we can classify them as:

- a) linear effects, which are wavelength depended
- b) nonlinear effects, which are intensity (power) depended.

1.1 Linear effects

Linear effects caused the majority losses of optical transmission signal through optical fibers. These linear effects are dispersion and optical signal loss called attenuation. The attenuation represents transmission loss, which means the decreasing level of the signal power with increasing length. Two kind of dispersion occurs in the optical fibers: modal and chromatic. This paper deal with single mode fibers and therefore modal dispersion, which occurs only in multi mode fibers, is not examined. The chromatic dispersion is caused by different traveling speed through fiber for different wavelength and it depends on the spectral width of the pulse. The broadening and phase shifting occurs in optical fibers due to the chromatic dispersion [1],[2],[3],[4].

1.2 Nonlinear effects

These effects play an important role in transmission of optical pulses through optical fiber. We can classify nonlinear effects:

- *Kerr nonlinearities*, which is self-induced effect in which the phase velocity of the wave depends on the wave's own intensity. Kerr effect describes change in refractive index of fiber due to electrical perturbation. Due to Kerr effect, we are able to describe following effects :
 - Self-phase Modulation (SPM) - effect that changes the refractive index of the transmission medium caused by intensity of the pulse.
 - Four Wave Mixing (FWM) - effect, in which mixing of optical waves rise a fourth wave, which can occur in the same wavelength as one of the mixed wave.

- Cross-phase effect (XPM) is effect where wave of light can change the phase of another wave of light with different wavelength. This effect causes spectral broadening.
- *Scattering nonlinearities*, which occurs due to inelastic scattering of a photon to lower energy photon. We can say that the energy of light wave is transferred to another wave with a different wavelength. Two effect appear in optical fiber:
 - Stimulated Brillouin Scattering (SBS) and Stimulated Raman Scattering (SRS) - effects that change variance of light wave into different waves when the intensity reaches certain threshold [5].

2 Simulation and design of the optical fiber

The presented simulation model comes out from the simulation model for optical communications introduced in [6]. Modeling was performed in MATLAB Simulink 2010 and GUI. The whole program is controlled by main screen, where user is able to perform adequate operations and it required only basic knowledge about the optical fiber. The program has two main function (calculation and simulation) so it represents two independent systems. The calculation part is used for calculating power of four wave mixing effect with the inserted parameters of fibers. This nonlinear effect occurs only in WDM system, so we assume that our system is using WDM in which three signals are transmitted in to the fiber. This part of the program is included into the main screen interface. The simulation part of the program simulates optical fiber with linear and selected nonlinear effects with On/Off Shift Keying (OOK) modulation technique. The simulation part of the program is being set by parameters which were inserted in main screen and calculated in the calculated part. The simulation part was using the Communication Blockset and Communication tools to simulate and create optical transmission path. In these tools we used already created blocks as modulators, generators, blocks with operation functions and measuring blocks. This program does not include designed blocks to simulate some of the linear and all of the nonlinear effects in optical fiber, but block AWGN partially compensate their functions.

2.1 Main screen and calculation part

As we mentioned before, the whole program starts with the main screen, which is shown on figure 1. The calculation output is power of FWM for one channel and it is calculated from the inserted parameters of optical fiber by using NLSE equation. These parameters are basic parameters of optical fibers. To ensure that the calculation will give correct values, we limit the input parameters.

The screenshot displays the main interface of the program, organized into several functional areas:

- Input parameters:** A grid of input fields for Wavelength [nm], space between wavelength [nm], Attenuation [dB/km], Length [km], Power of examined signal [mW], Power of additional signal 1 [mW], Power of additional signal 2 [mW], Mode Field Diameter [μW], Chromatic dispersion [ps/(nm.km)], Polarization Mode dispersion [ps/km^{1/2}], Refractive index of cladding [], Number of symbols [10⁴ Bit], Refractive index of core [], and Spectral width [nm].
- Transmission rate:** Radio buttons for 1 Gbit/s, 10 Gbit/s, and 100 Gbit/s, with separate sections for 'examined signal', 'additional signal 1', and 'additional signal 2'.
- Modulations:** Radio buttons for OOK (selected), DBPSK, DQPSK, and FSK.
- Type of signal:** Radio buttons for Quick rise/fall edge (selected), Slow rise/fall edge, and Ideal.
- Calculated parameters:** Output fields for Effective length [km], Dispersion coefficient [ps²/km], Birefringence [m⁻¹], Efficiency [], Nonlinear coefficient [km⁻¹ W⁻¹], Power of 4th wave [mW], Power of 4th wave [dBm], and Power of 4th wave [dB].
- Control panel:**
 - Calculation:** Buttons for Calculate, Set default, and Reset.
 - Simulation:** Buttons for Start simulation, Run simulations, Stop simulations, and Close simulations.
 - Buttons for Close program and Help.

Figure 1: A main screen of the program

2.2 Simulation part

The simulation part allows the simulation of different modulation techniques through optical fiber with given parameters and system performance [7]. To run the simulation part, the input parameters and power parameter of four wave mixing must be set. In this section we will show how the signal changes as passes through the system. For this purpose we will consider these parameters of the system: three source generator with the power 1 mW at wavelengths of 1550,5 nm, 1551 nm and 1551,5 nm, the fiber length 10 km, the dispersion coefficient 18 ps/(nm.km), the attenuation 0,21 B/km. To simulate a realistic optical transmission medium we used four effects that influence the transmission path - attenuation, limited bandwidth, dispersion and four wave mixing effect. The design of the simulation which simulates OOK modulation is shown on figure 2.

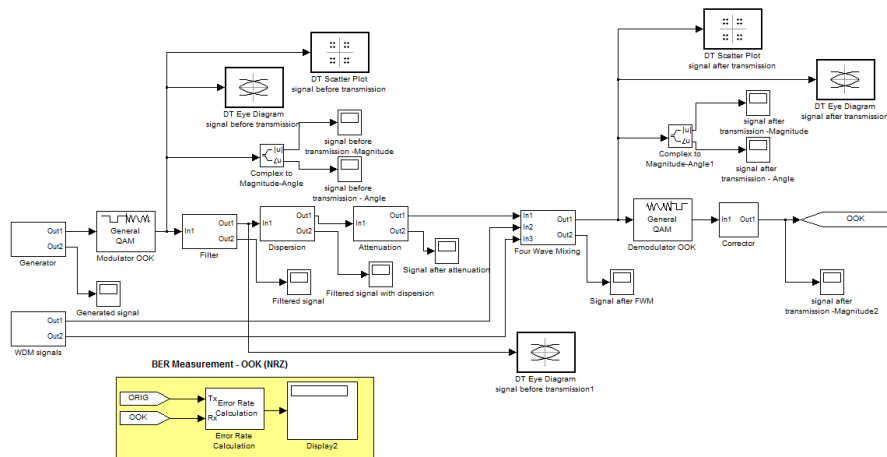


Figure 2: A scheme of the OOK modulation

As a source we used a Bernoulli generator which generates two pulses “1” and “0”. The original model also used a Bernoulli generator, but it was used in framework mode, which did not work with the dispersion part. To compare the input signal with output, both signals must be brought to the corrector, which delay the original signal with the transmitted signal. The graph of generating signal with the involvement scheme is shown on figure 3. The blocks responsible for the delay are filter and dispersion.

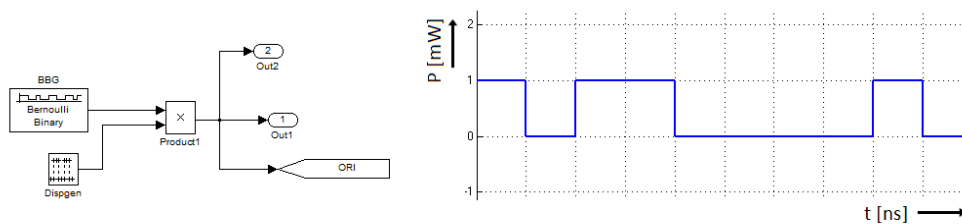


Figure 3: An ideal signal generated by the Bernoulli generator

After being generated the ideal signal is modulated by the OOK modulation, which is shown on figure 4 and the course of the signals is shown on figure 5. These modulations are part of the MATLAB Simulink. The aim of this program is to show the realistic optical fiber in the realistic system without infinity bandwidth. Assuming finite bandwidth, we filtered signal with the appropriate filters and the scheme of filter is shown on figure 6. The program involves two options for filtering. The first filtration changed the signal with higher rise and fall edge. This kind of signal is mostly generated with expensive sources used in core networks. The second option is a signal with slower rise and fall edges. This kind of signal can be generated with LED diode and both filtrations are shown on figure 7.

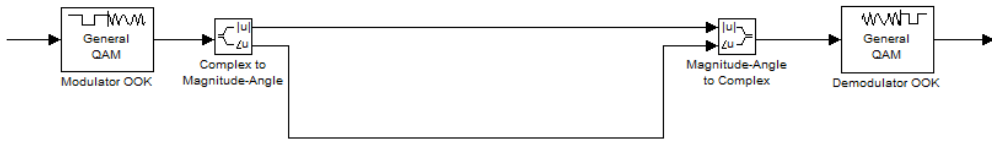


Figure 4: A scheme of modulator and demodulator blocks

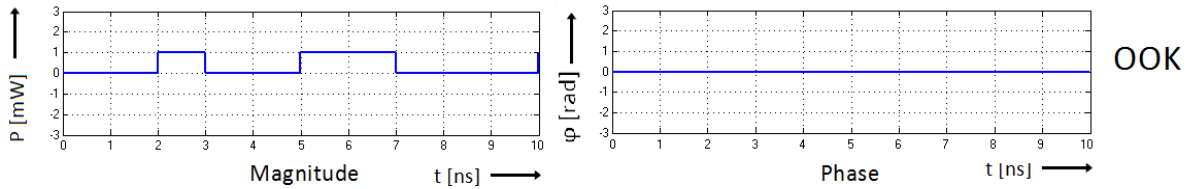


Figure 5: The modulated OOK signal

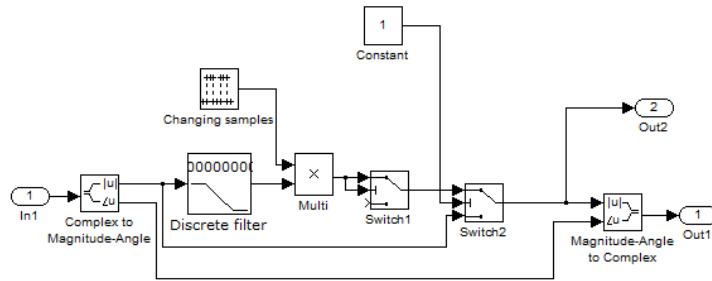


Figure 6: A scheme of the filter block

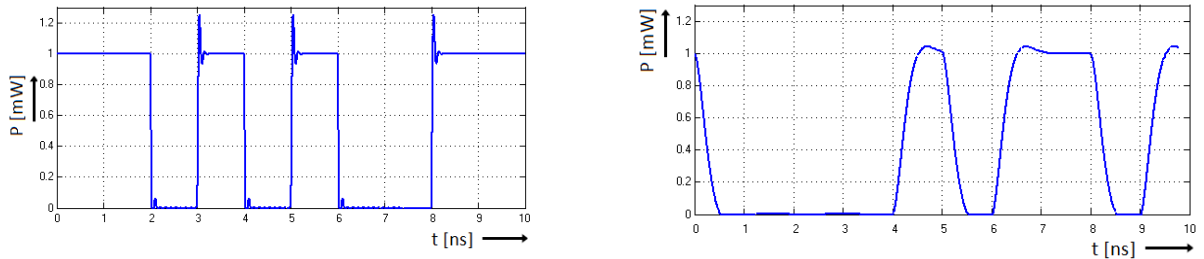


Figure 7: The OOK filtered signal – a laser diode (left) and a LED diode (right)

We use the dispersion block after we filter the signal with an appropriate filters. This dispersion block causes the original signal to expand in the time domain and phase shift occurs due to chromatic dispersion. The dispersion scheme is shown on figure 8. In this system, the value of dispersion is given by 18 ps/(nm.km). Because we are using this 10 km system the signal will broader by value of 180 ps/(nm.km). The influence of dispersion is shown on figure 9. On this figure we compare magnitudes between the signal without dispersion and signal with dispersion. The power of signal on figure 9 is attenuated due to bordering of pulse and pulse energy.

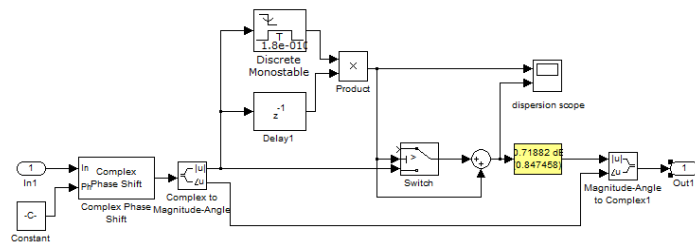


Figure 8: A scheme of the dispersion block

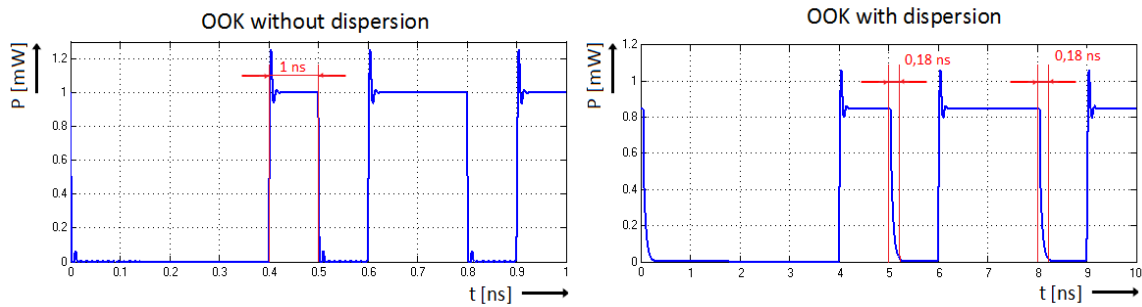


Figure 9: A comparison of the OOK signal with and without the dispersion

The next effect we use is attenuation. For this effect we used block which is already part of MATLAB Simulink. The scheme for attenuation is shown on figure 10. In the realistic system, the attenuation decreases the amplitude (magnitude) of the signal. For our fiber, the attenuation is 0,21 dB/km and because we are using the 10 km distance, our total signal attenuation is 2,1 dB. A comparison of the signal with attenuation and the signal without attenuation is shown on figure 11.

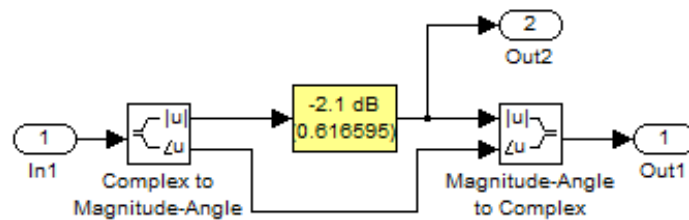


Figure 10: A scheme of the attenuation block

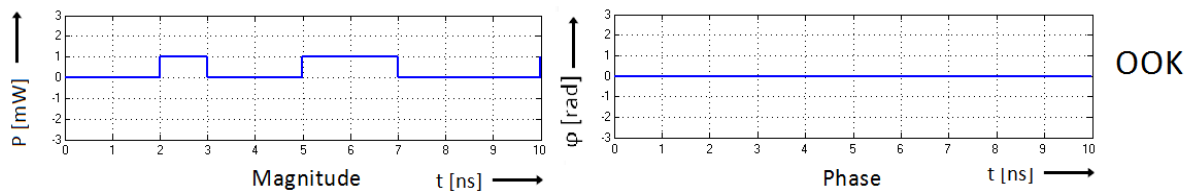


Figure 11: A comparison of the signal with and without the attenuation

The last effect of the simulation is the Four Wave Mixing. The FWM block is inserted after linear effects. This FWM effect occurs only in WDM systems and therefore we generate additional two signals with same modulation techniques. Generated signals are brought into the FWM block where all the signals are mixed and new generated FWM signal is created with the power given by parameters introduce in the main screen. The FWM schemas are shown on figure 12. The FWM effect differs depending on the power of the fourth wave and transmission rates of all mixed signals. The FWM effect on the OOK modulation with the quick rise/fall edge and the FWM effect on the OOK modulation with the slow rise/fall edge are shown on figure 13. We assume that a power of the FWM has only real part and therefore it affects only the magnitude. We observe that if a dispersion coefficient value of SSMF optical fibers is higher than the 10 ps/(nm.km) and the channel spacing is more than 0,5 nm, then the FWM signal power is negligible compared to the optical signal power. These values are typical for Standard Single-Mode Fibers (SSMF), which used for long distances. However, when we use these dispersion values then the speed per channel is limited to 1 – 10 Gbit/s.

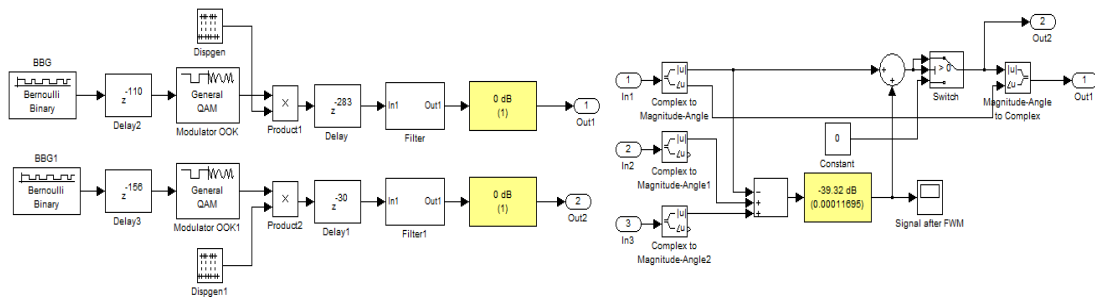


Figure 12: Schemes of the FWM blocks

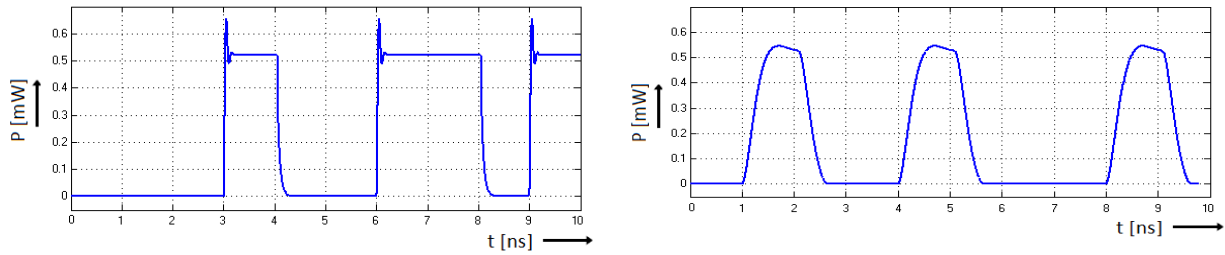


Figure 13: The OOK signal (quick rise/fall edge) and the OOK signal (slow rise/fall edge) with the FWM effect for the SSMF

Many optical transmission systems used Non-Zero Dispersion Shifted Fibers (NZDSF) with dispersion values are from 0,1 to 6 ps/(nm.km). The FWM effect on these kinds of fibers has higher values than in the SSMF. This causes the lower SNR ratio as shown on figure 14 for the OOK modulation with quick rise/fall edges and for the OOK modulation with slow rise/fall edges. The signal shape depends on the modulation format used by neighboring signals and on the transmission rate. We assume that the neighboring signals are using the same modulation format as examined signal.

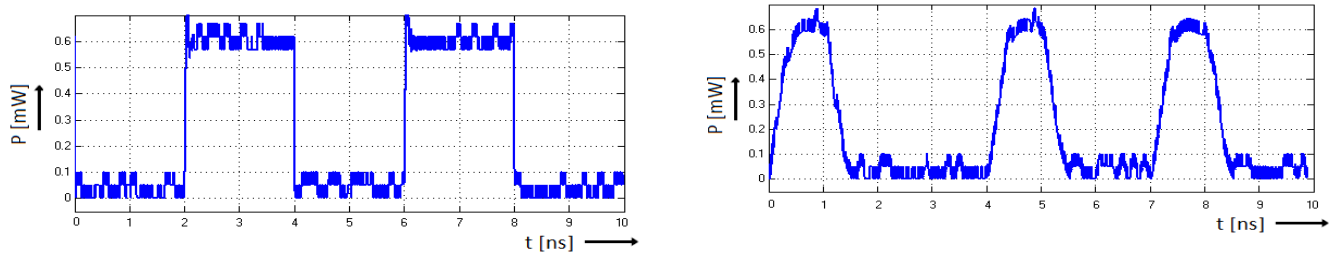


Figure 14: The OOK signal (quick rise/fall edge) and the OOK signal (slow rise/fall edge) with the FWM effect for the NZDSF

After the signal pass through fiber, it gets delayed. To compare the input and the output signal, both signals must be delayed with same time. For this reason we add a corrector block which delays the input signal and then we compare the signals in comparison block. The schemes of these blocks are shown on figure 15. The simulation shows the Bit Error Rate (BER) of the system by comparing the input with the output signal bit by bit. The number of compared bits can be set in main screen.

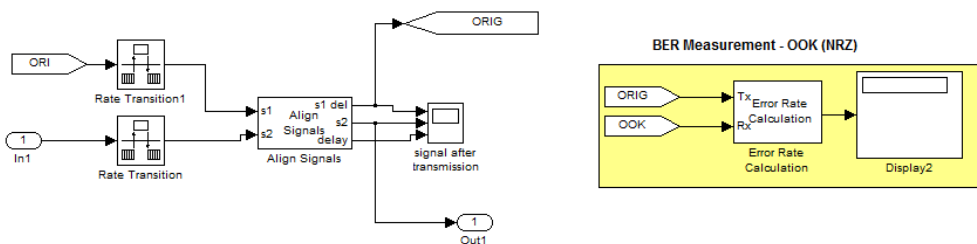


Figure 15: Schemes of the corrector and comparison block

The simulation part includes eye diagrams which allow the calculation of the BER and make it easier to view the signal. The eye diagram is an oscilloscope display of the transmitted digital signal, which is repetitively sampled to get a good representation of its behavior. The eye diagram is often used to look at the signal before transmission, to assure that the signal is generated properly, but mostly it is used to look at the received signal to evaluate the signal quality. Careful analysis of this visual display can give the user a first-order approximation of signal-to-noise. Eye diagrams before and after transmission for OOK modulation are shown on figure 16.

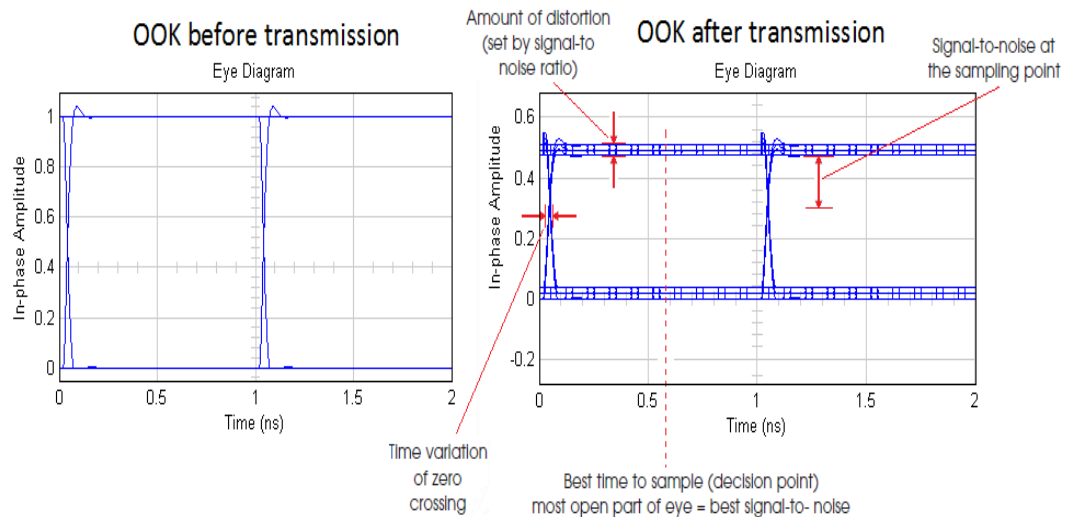


Figure 22: OOK eye diagrams before and after transmission

The BER calculation for this system was zero (demodulator was set to hard decision detection), because the simulation doesn't include some of nonlinear effects and dispersion was in limits of detections. When we enlarge the length of fiber, the dispersion and attenuation rise linearly and in some cases we were unable to detect bits correctly [7].

3 Conclusion

Our main goal is to present various courses for the OOK modulation technique through optical transmission medium. This simulation involves linear effects and the FWM nonlinear effect, but in the near future we would like to extend this simulation for other nonlinear effects and thus results will be closer to real systems. Such a program would allow an overview of the possibilities of modulation. Another task would be adding other modulation techniques such as MSK, QAM and Zehn-Manchester modulation, which propagate the signal in a different way. Additionally the program allows a further understanding of the issues of nowadays optical transmission systems.

Acknowledgment

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