Impact of Filter Characteristics and Optical Signal Parameters on Interchannel Crosstalk

Agnieszka Kowalczyk and Krzysztof Perlicki

Abstract—In this paper we present analysis of the influence of filter characteristics of Wavelength Division Multiplexing network components and transmission parameters over interchannel crosstalk for symmetric and asymmetric transmission. The simulation was carried out for bit rate 10 Gb/s, 40 Gb/s and 100 Gb/s considering the following modulations: DPSK, DQPSK and OOK. The obtained results show that OOK and DQPSK modulation are better than DPSK modulation in terms of crosstalk occurring during the transmission of signals in Wavelength Division Multiplexing systems.

Keywords—fiber optics transmsission, Wavelength Division Multiplexing, optical filter, interchannel crosstalk

I. Introduction

OPTICAL TRANSPORT CAPACITIES have been growing significantly in the last few years following the explosive demand for high bandwidth Internet services. The data transmission rates are now moving from 10 Gb/s to 40 Gb/s and 100 Gb/s on a wavelength (optical channel) and wavelengths are more densely spaced. The optical WDM (Wavelength Division Multiplexing) transmission systems is evolving from closed systems to open systems, where the optical layer is designed in a way that allows new transmitters and receivers to be connected to it without requiring changes to the physical layer not to the planning and management tools that are needed to operate it. [1], [2]. Nowdays, the single WDM transmission system must be able to transmitted different optical signal modulation formats and different bit rates [3], [4]. One of the most important issues for the design of the current and future WDM systems is relationship between transmitted signal modulation format, bit rate, optical channel spacing and parameters of multiplexer and demultiplexer filter [5]. In this paper, we present a numerical simulation of the impact of transmitted optical signal parameters and parameters of multiplexer and demultiplexer filter on WDM channels crosstalk. The simulation setup is focused on optical transmission system with 10 Gb/s, 40 Gb/s or 100 Gb/s optical channels. The following signal modulation formats are taken into account: DPSK (Differential Phase Shift Keying), DQPSK (Differential Quadrature Phase Shift Keying) and OOK (On-off Keying) [6].

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II. Numerical Simulations

The simulation setup is shown in Fig. 1. The simulated setup consists of: 4 transmitters, multiplexer 4×1, demultiplexer 1×4 and fiber optics link SSMF (Standard Single Mode Fiber). In the system setup 4 channels were used, which were separated with 50 GHz channel spacing. The channel frequencies were selected according to ITU-T G.694.1 recommendation (193.05 THz, 193.10 THz, 193.15 THz, 193.20 THz) [7]. The 3 dB bandwidth of the multiplexer and demultiplexer filter varied between 20 GHz and 60 GHz for all tested modulations and bit rates. There were considered two shapes of filter transfer function: gaussian and rectangular. For gaussian filter the filter order changed from 1st to 6th order. In case of a rectangular filter stopband attenuation was changed from 20 to 70 dB. Default filter had gaussian characteristics of second order. Due to the research the effects of transmission parameters and filters used in the system over interchannel crosstalk, nonlinear effects such as stimulated Raman scattering, stimulated Brillouin scattering, self-phase and cross-phase modulation and four wave mixing have been omitted. Additionally, optical loss, chromatic and polarization dispersion have been also neglected. Optical crosstalk was calculated for the Port No. 2 (Fig. 1). The simulation was carried out for bit rate 10 Gb/s, 40 Gb/s and 100 Gbt/s considering the following modulations: DPSK, DQPSK and OOK. Two cases were considered as well:

Case 1: Transmitted signals had the same bit rate for each channel.

Case 2: In the channel, which was considered for calculating crosstalk, the bit rate was 10 Gb/s, while in the adjacent channels signals were transmitted with a higher bit rate: 40 Gb/s or 100 Gb/s.

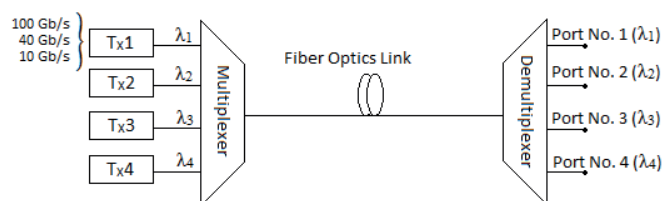Numerical simulations were realized with VPItranmission Maker (VPIsystems Inc.)

Fig. 1. Diagram of simulated DWDM system RX1, RX2 – receivers Schematics of simulated system; Tx1, Tx2, Tx3, Tx4 are transmitters of each wavelenght: λ_1, λ_2, λ_3, λ_4. Channel at the Port no.2 (λ_2) was considered for calculating interchannel crosstalk.
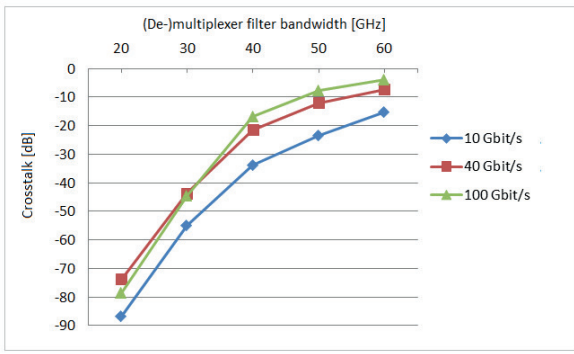
Fig. 2. Crosstalk values versus demultiplexer and multiplexer filter bandwidth for DPSK modulation, second order gaussian filter and different bit rates.
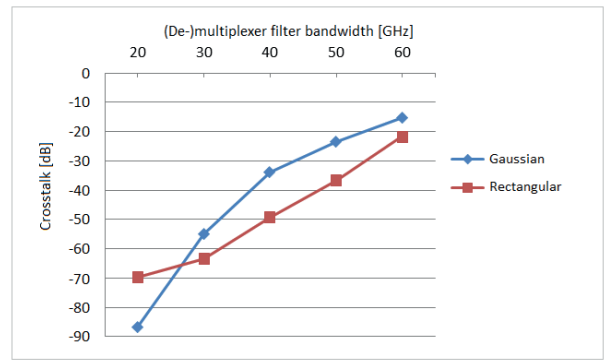

Fig. 5. Crosstalk values versus demultiplexer and multiplexer filter bandwidth for DPSK modulation, 10 Gb/s bit rate and different types of filters: second order gaussian filter and rectangular filter with stopband attenuation 30 dB.
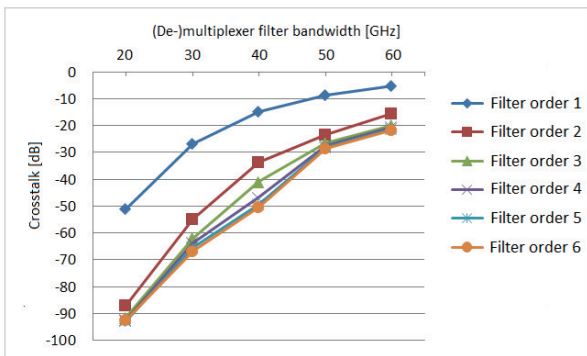

Fig. 3. Crosstalk values versus demultiplexer and multiplexer filter bandwidth for DPSK modulation, 10 Gb/s bit rate and different gaussian filter order.
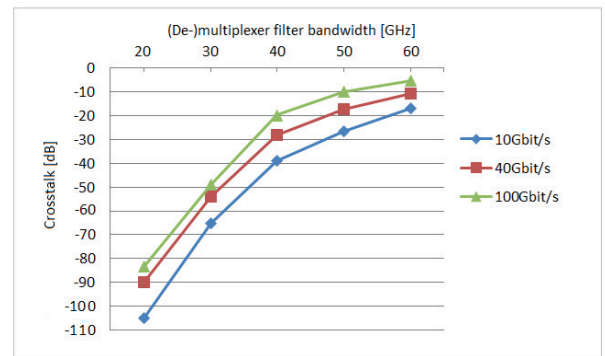

Fig. 6. Crosstalk values versus demultiplexer and multiplexer filter bandwidth for DQPSK modulation, second order gaussian filter and different bit rates.

III. NUMERICAL RESULTS

Figs. 2-15 show the results for case 1 (symmetric transmission). Here, transmitted signals had the same bit rate for each channel.

Simulations were performed for the WDM system shown in Fig. 1.

From Figs. 2, 6, 10 it can be concluded that level of crosstalk depends largely on bit rate in channel. This is because of the fact that for higher bit rate spectrum becomes wider. Obtaining 10 Gbit/s required filter bandwidth of approximately 55 GHz

for all tested modulation. For 40 Gbit/s it was necessary to use narrower filter bandwidth. In case of DPSK modulation and bit rate 100 Gbit/s acceptable level of crosstalk was achieved for around 40 GHz of filter bandwidth. For 50 GHz crosstalk amounted -8dB. Under the same conditions, for DQSPK modulation, achieved result was -10 dB. From the graph shown in the figure 10 (OOK modulation) can be read that for 50 GHz we obtained -15 dB. In all cases, the use of a filter with a bandwidth of 60 GHz, was resulting in the occurrence of excessive crosstalk. Only the filter bandwidth below 40 GHz
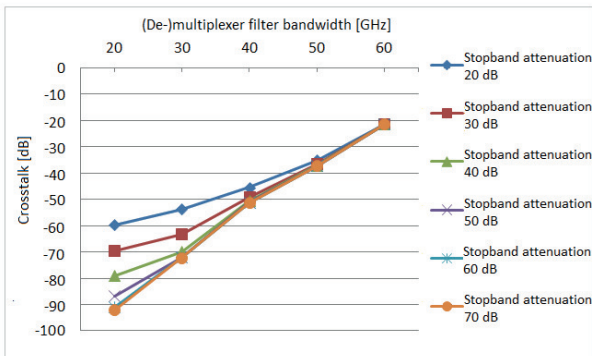

Fig. 4. Crosstalk values versus demultiplexer and multiplexer filter bandwidth for DPSK modulation, 10 Gb/s bit rate and different stopband attenuation of rectangular filter characteristics.
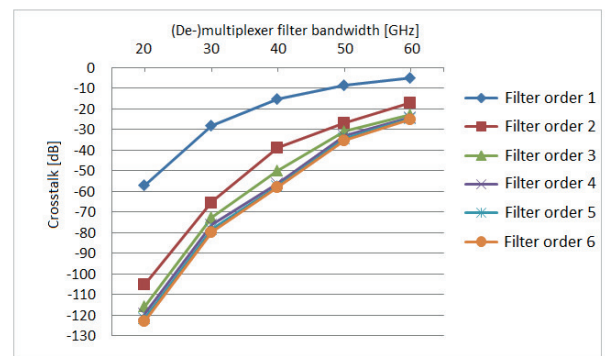

Fig. 7. Crosstalk values versus demultiplexer and multiplexer filter bandwidth for DQPSK modulation, 10 Gb/s bit rate and different gaussian filter order.
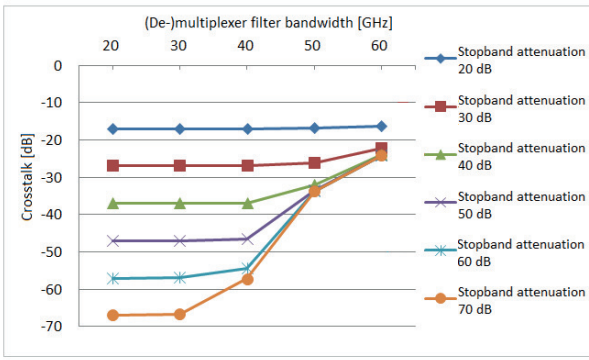
Fig. 8. Crosstalk values versus demultiplexer and multiplexer filter bandwidth for DQPSK modulation, 10 Gb/s bit rate and different stopband attenuation of rectangular filter characteristics.
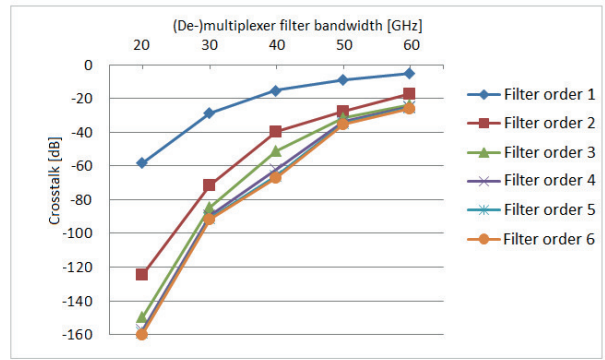

Fig. 11. Crosstalk values versus demultiplexer and multiplexer filter bandwidth for OOK modulation, 10 Gb/s bit rate and different gaussian filter order.
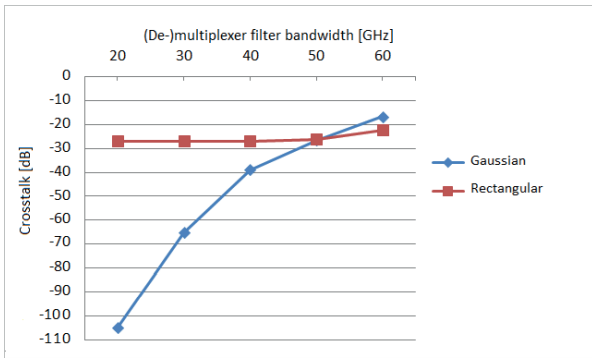

Fig. 9. Crosstalk values versus demultiplexer and multiplexer filter bandwidth for DQPSK modulation, 10 Gb/s bit rate and different types of filters: second order gaussian filter and rectangular filter with stopband attenuation 30 dB.
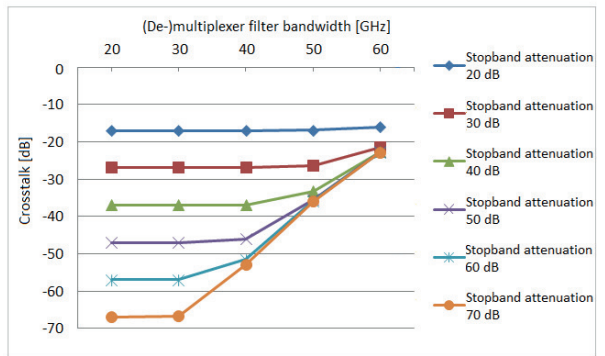

Fig. 12. Crosstalk values versus demultiplexer and multiplexer filter bandwidth for OOK modulation, 10 Gb/s bit rate and different stopband attenuation of rectangular filter characteristics.

signal transmission allowed rates of 100 Gbit/s. This research proved that for symmetric transmission the best results were obtained for OOK modulation. The simulation and analysis of the results showed that in most cases DQPSK modulation was better than DPSK modulation in terms of crosstalk occurring during the transmission of signals in WDM networks. This is mainly due to the fact that at the same bit rate DQPSK modulation has two times narrower bandwidth. Narrow-band filtering allowed crosstalk to be at the acceptable level (-20

dB) [8]. Simulation has also shown that the maintenance of the acceptable transmission quality for filters with a width greater than 40 GHz requires employment of 100 GHz channel spacing. For rectangular filter it was shown that stopband attenuation might play significant role in obtaining acceptable crosstalk as well. The best results were achieved for stopband attenuation equal to 70 dB. With the decrease of stopband attenuation the increase of crosstalk level was observed. It means that the highest level of crosstalk was obtained in
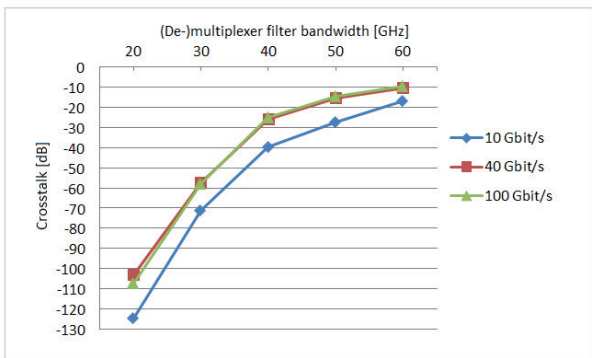

Fig. 10. Crosstalk values versus demultiplexer and multiplexer filter bandwidth for OOK modulation, second order gaussian filter and different bit rates.
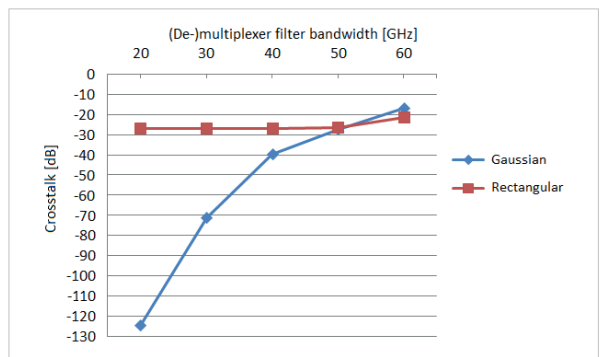

Fig. 13. Crosstalk values versus demultiplexer and multiplexer filter bandwidth for OOK modulation, 10 Gb/s bit rate and different types of filters: second order gaussian filter and rectangular filter with stopband attenuation 30 dB.
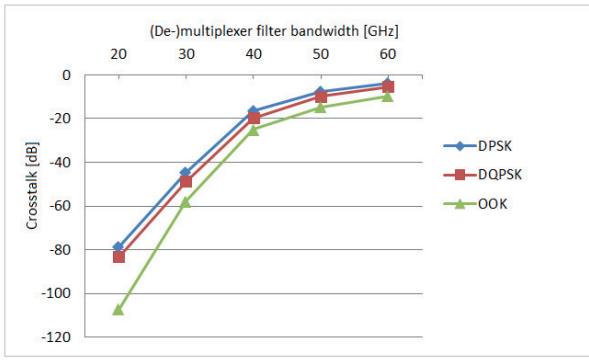
Fig. 14. Crosstalk values versus demultiplexer and multiplexer filter bandwidth for 100 Gb/s bit rate, second order gaussian filter and different types of modulation.
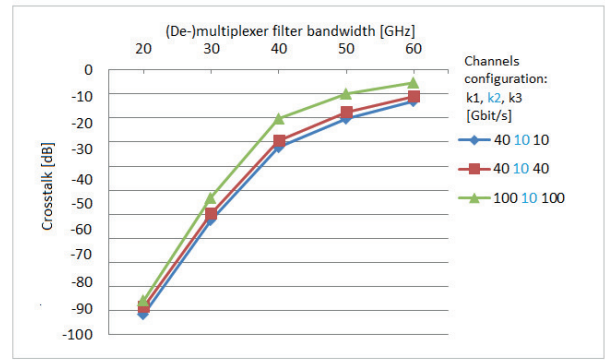

Fig. 17. Crosstalk values versus demultiplexer and multiplexer filter bandwidth for DQPSK modulation, second order gaussian filter and different configuration of bit rates in adjacent channels.
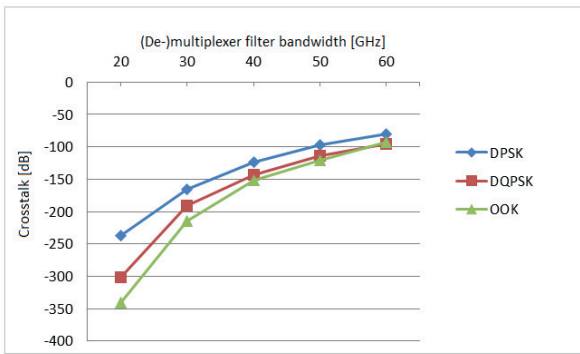

Fig. 15. Crosstalk values versus demultiplexer and multiplexer filter bandwidth for 100 Gb/s transmission, second order gaussian filter and different types of modulation (100 GHz channel spacing).
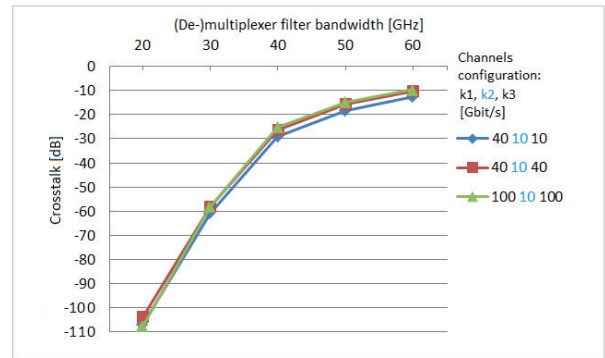

Fig. 18. Crosstalk values versus demultiplexer and multiplexer filter bandwidth for OOK modulation, second order gaussian filter and different configuration of bit rates in adjacent channels.

case of 20 dB stopband attenuation for all modulations. For gaussian filters of 4th-6th order there were achieved the best results. In case of filters 1st-3rd order level of crosstalk was excessively high. This is because the lower order transfer functions have much gentler slopes, which contributes to the higher power signal outside the desired band of gaussian filter. In case of higher order filters slopes are steeper. This is the reason why signal power is better attenuated between two channels. Therefore, each channel is properly separated

from the others. Comparison between gaussian and rectangular filter for DPSK modulation was shown in figure 5. There were compared: rectangular filter with stopband attenuation of 30 dB and 2nd order gaussian filter. In this case a better solution was the rectangular filter, for which obtained level of crosstalk was lower than in case of a gaussian filter. For example for 50 GHz bandwidth of gaussian filter, crosstalk was about -23 dB and for the rectangular was around 15 dB lower.

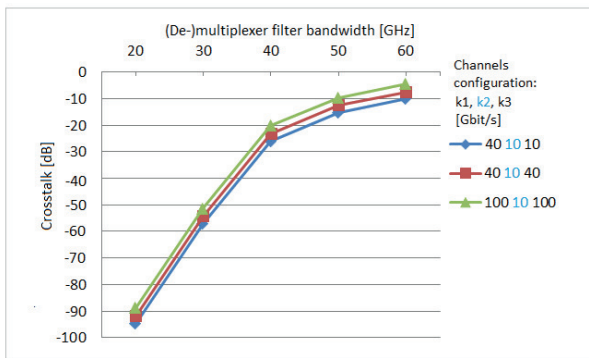Fig. 16. Crosstalk values versus demultiplexer and multiplexer filter bandwidth for DPSK modulation, second order gaussian filter and different configuration of bit rates in adjacent channels.
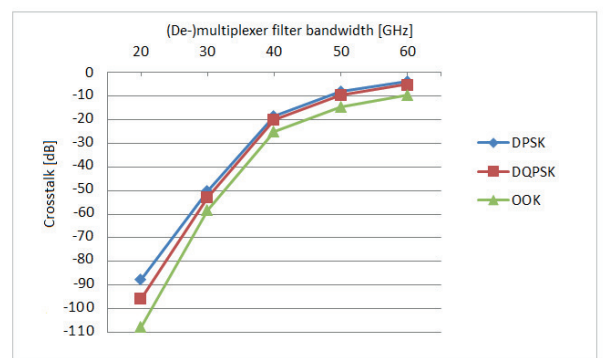

Fig. 19. Crosstalk values versus demultiplexer and multiplexer filter bandwidth for different types of modulation, second order gaussian filter and bit rate 10 Gb/s in tested channel and 100 Gb/s for adjacent channels.

TABLE I
BIT RATES CONFIGURATION FOR THE ASYMMETRIC TRANSMISSION

Number of channel	Channel 1	Channel 2	Channel 3
	40 Gb/s	10 Gb/s	10 Gb/s
Bit Rate	40 Gb/s	10 Gb/s	100 Gb/s
	100 Gb/s	10 Gb/s	100 Gb/s

Only for narrow-band filtering the situation was different and rectangular filter had worse results. For DQPSK modulation plots look slightly different (Fig. 9). The experimental results were much better in case of use of gaussian filter than the rectangular. Only filter bandwidth of 60 GHz for rectangular characteristic of filter turned out to be better. Below this value, the level of crosstalk for the 2nd order gaussian filter decreased significantly and at 20 GHz band of the filter is less than -100 dB. For OOK modulation the best results were achieved for gaussian filter as well. Figs. 16-19 show the results for case 2 (asymmetric transmission). In the channel, which was considered for calculating crosstalk, the bit rate was 10 Gb/s, while in the adjacent channels signals were transmitted with 40 Gb/s or 100 Gb/s. There was also used 2nd order gaussian filter in simulation setup. Tab. I presents configuration of channels used for asymmetric transmission. Simulations were performed for the WDM system shown in Fig. 1.

The dependency presented in the Figs. 13-16 indicates an increase in level of crosstalk with the transmission at higher bit rate in adjacent channels. As expected the lowest crosstalk was obtained for bit rate of 40 Gbit/s in channel 1 and 10 Gbit/s in channel 3 and the transmission of 100 Gbit/s on both adjacent channels resulted in the occurrence of the highest crosstalk. For DQPSK modulation level of crosstalk was slightly lower than for DPSK. For 50 GHz (de)multiplexer filter bandwidth and transmission in channels 1-40 Gbit/s, 2-10 Gbit/s and 3-40 Gbit/s, the level of crosstalk was equal to -18 dB. This value was obtained for DPSK modulation with (de)multiplexer bandwidth of 45 GHz. It means that receiving the same results for DPSK modulation requires narrower bandwidth of filter. In case of OOK modulation, the obtained results show improvement over previous tested modulations. Figure 19 illustrates comparison of the level of crosstalk for asymmetric transmission for the three tested modulations. In this situation for 40 GHz of the filter bandwidth of (de)multiplexer, bit rate 10 Gbit/s, transmission of 100 Gbit/s in adjacent channels and OOK modulation data transfer was possible – the level of

crosstalk was around -25 dB. Under the same conditions for DPSK and DQPSK modulation, crosstalk was -20 dB. So for asymmetric transmission level of crosstalk is the lowest for OOK modulation. It can also be concluded that acceptable crosstalk is achieved for transmission 100 Gb/s in adjacent channels only with the narrow-band filtering (30 GHz filter bandwidth). For lower bit rates bandwidth of 40 GHz-50 GHz is sufficient for all modulations.

IV. CONCLUSION

The obtained results indicate that for asymmetric and symmetric transmission the best results were obtained for OOK modulation. The simulation and analysis of the results showed that in most cases DQPSK modulation is better than DPSK modulation in terms of crosstalk occurring during the transmission of signals in WDM networks. It was also proved that for DPSK modulation there can be achieved better results for rectangular filter. In case of DQPSK and OOK modulation gaussian filter turned out to be better choice. Another drawn conclusion is that narrow-band filtering plays significant role in obtaining allowable level of crosstalk. Improvement of results may also be achieved by increasing the channel spacing from 50 GHz to 100 GHz.

REFERENCES

[1] O. Gerstel, R. Cassata, and L. Paraschis, "Operational Solutions for an Open DWDM layer," in *Conference on Optical Fiber Communication/National Fiber Optic Engineers Conference, NthF1*, San Diego, USA, 2009.

[2] S. Melle, G. Bennett, and C. Liou, "Alien Wavelength Transport," in *An Operational and Economic Analysis Conference on Optical Fiber Communication/National Fiber Optic Engineers Conference, NthF2*, San Diego, USA, 2009.

[3] A. Hodzic and M. Winter, "Optimized Filtering for 40-Gb/s/Ch-Based DWDM Transmission Systems Over Standard Single-Mode Fiber," *Photonics Technology Letters*, vol. 7, pp. 1645–1647, 2011.

[4] S. Suzuki and Y. Kokubun, "Design Rule of Wavelength Filter Bandwidth and Pulsewidth for Ultimate Spectral Efficiency Limited by Crosstalk in DWDM Systems," *Photonics Technology Letters*, vol. 11, pp. 1002–1004, 2003.

[5] K. Perlicki, "Impact of an alien wavelength on wavelength division multiplexing transmission quality," *Photonics Letters of Poland*, vol. 3, pp. 118–120, 2012.

[6] A. Kowalczyk, "Wpływ parametrów elementw filtracyjnych na jakość pracy systemów WDM," in *Bachelor of science thesis, Institute of Telecommuniacations, Warsaw University of Technology*, Warsaw, Poland, 2013.

[7] ITU-T G.694.1, "Spectral grids for WDM applications," in *DWDM frequency grid*, Geneva, Switzerland, 2/2012.

[8] G. P. Agrawal, *Fiber-Optic Communication Systems*. New York, USA: A John Wiley & Sons, Inc., 2002.