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МОДЕЛИРАНЕ И ОПТИМИЗАЦИЯ НА МНОГОКАНАЛНИ ОПТИЧНИ КОМУНИКАЦИОННИ ЛИНИИ

MODELLING AND OPTIMIZATION OF MULTICHANNEL OPTICAL COMMUNICATION LINES

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Abstract
The paper presents a modeling and optimization process for multi-channel optical communication lines. For this purpose, a 4-channel optical WDM network is considered at a 40 Gbps transmission rate. The objective is to achieve optimization of the optical transmission line parameters when using basic modulation formats, according to criteria providing a minimum value of BER (Min. BER) or maximum Q factor (Max. Q).

Keywords: WDM, NRZ, RZ, OSNR, SMF.

INTRODUCTION

The modern optical communications networks are based on WDM technology and its varieties [3, 9].

In a large number of cases, the necessary design and calculations use a combination of specialized calculation methods and complex specialized software tools [1, 2, 5-8]. Taking into account the multiple interconnected parameters, achieving an optimal solution for the parameters of the communication system is an extremely complex task.

The main purpose of this work is modeling, simulation and optimization of a 4-channel optical communication line with spectral multiplexing at 40 Gbps and different output data: optical line length, optical power of transmitters and modulation formats used (NRZ and RZ).

MODELING OF MULTICHANNEL OPTICAL COMMUNICATION LINE

A. Model description

The implementation of a simulation model of a multichannel WDM system for the study of the parameters and characteristics of the transmitted optical signals will be described. The selection and setting of the individual blocks in the model is consistent with the following initial conditions:

- number of multiplexing channels: 4;
- wavelength range: λ = 1550 nm;
- number of amplifying sections: 5;
- line length: 500 km
- type of optical fiber: SMF;
- optical signal modulation format: NRZ, RZ;
- channel bandwidth: 40 Gbps.

It is used Optiwave OptiSystem as a modeling software, which is a comprehensive software package for planning, designing, testing and simulation of the optical links at the physical layer of modern optical networks [1, 2, 4, 6].

For the realization of a 4-channel optical system, it is necessary to multiplex / demultiplex the optical signals from 4 separate optical signal sources. For this purpose, 4 externally modulated optical transmitters were created, each containing a continuous wave laser source, random bit sequence generator, NRZ or RZ signal encoder and Mach-Zender optical signal modulator – Fig. 1.

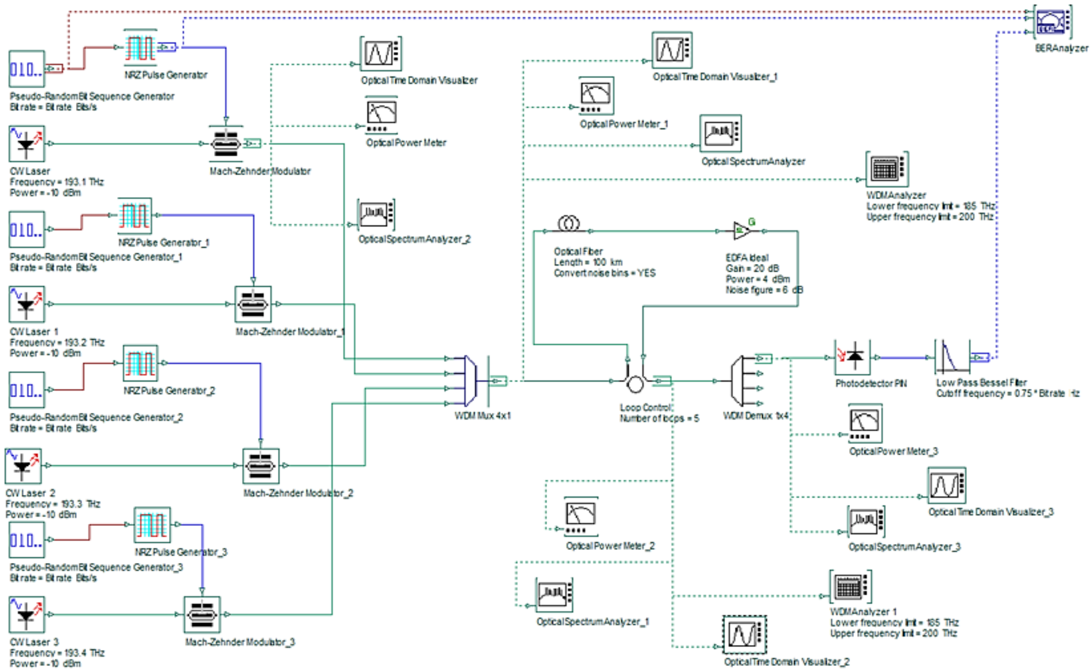

Fig. 1. *Simulation model of a 4-channel optical communication line with spectral multiplexing*

The frequency / wavelength settings for each of the optical transmitters are summarized in Table 1.

Table 1. *Frequency / wavelength settings of the optical transmitter in 4-channel WDM system*

Optical transmitter	Carrier wavelength, nm	Frequency, THz
CW laser 0	1552,52438115	193,1
CW laser 1	1551,720797101	193,2
CW laser 2	1550,91804449	193,3
CW laser 3	1550,116122027	193,4

In RZ coding, a RZ block impulse generator is used instead of the NRZ pulse generator (Fig. 1).

The resulting 4 NRZ/RZ modulated optical signals at different wavelengths in the 1550 nm range have to be spectrally multiplexed using a WDM 4x1 multiplexer.

The length of each amplifying section is set by the length of the optical fiber in the Optical Fiber block (Fig. 1). The length of the optical fiber for the simulation model is 100 km. The fiber optic block settings are as follows:

– attenuation of the fiber: 0,2 dB/km;
– dispersion: 17 ps/nm/km;
– effective area: 80 μm^2;
– refractive index of the fiber: $n_2 = 2{,}6.10^{-20}$ m^2/W;
– fiber length: 100 km.

Five amplifying sections are modeled, which sets the overall length of the 500 km.

An EDFA amplifier performs the amplification in each amplifying section with the following settings:

– amplifier gain: 20 dB;
– output optical power level: 4 dBm;
– noise figure: 6 dB.

The following blocks are used to create an optical receiver:

– PIN photodetector with sensitivity –25 dBm;
– Low Pass Bessel Filter, which filters the noise after the decision device in the optical detector; the filter parameters are: 4th order filter wit cut-off frequency of 0,75* Bit rate = 30 GHz.

The full model by which the simulation studies of the 4-channel WDM system will be realized in the case of NRZ encoding the optical signal is shown in Fig. 1.

The following virtual measuring blocks are used for the study:

– optical time domain visualizer;
– optical spectrum analyzer;
– BER analyzer;
– WDM analyzer;
– optical power meter.

B. Optimization task

The basic criteria for optical communication lines with spectral multiplexing in an optimal case search are the following:

– maximum permissible BER value: it is accepted $BER = 1.10^{-12}$;
– Q-factor value at BER admissible value: $Q > 6$;
– optical signal-to-noise ratio (OSNR): $OSNR > 12$.

As a further criterion in the evaluation of the system parameters, the basic characteristics of the optical signal are used:

– eye-diagram;
– spectral characteristics of the optical signal - to evaluate the effects of various effects such as signal dispersion, four-wave mixing, and the noise level in the channel;
– time diagrams of the optical signal – to evaluate the interference, group velocity dispersion, etc.

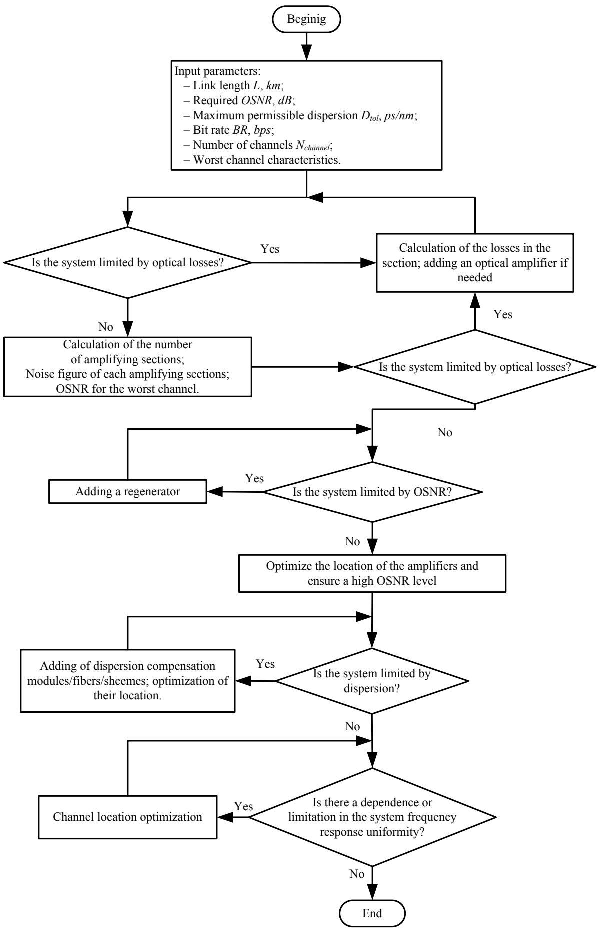

***Fig. 2.** WDM optical line optimization algorithm*

Based on these characteristics, in Fig. 2 is shown an algorithm for optimal planning and optimization of parameters for WDM optical communication line.

RESULTS

In Fig. 3 and Fig. 4 are shown graphical dependencies for determining the optimum power of optical transmitters in the case of RZ and NRZ modulation.

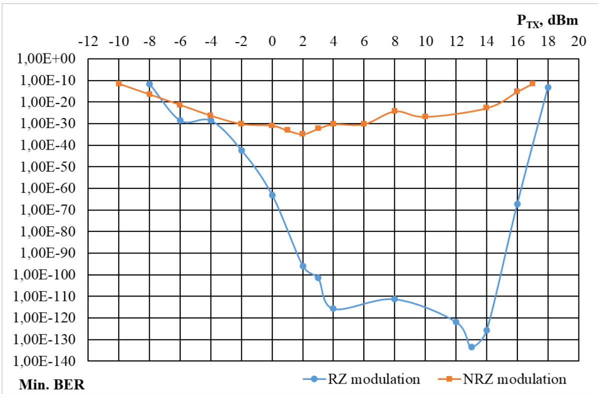

***Fig. 3.** Comparative graphic dependency $P_{TX} = f(Min.\ BER)$*

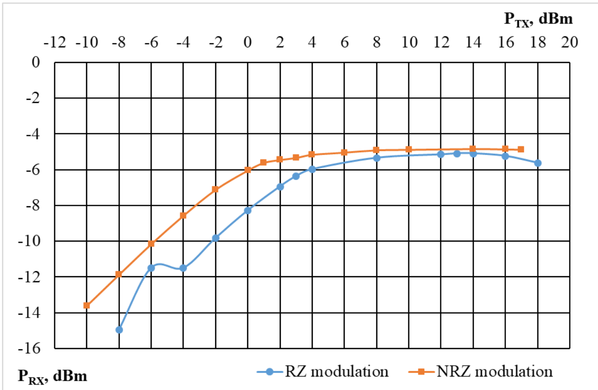

***Fig. 4.** Comparative graphic dependency $P_{TX} = f(P_{RX})$*

As can be seen from Fig. 3 and Fig. 4, using RZ modulation, much better BER (the highest minimum) or Q-factor (the highest maximum) values are achieved for a wide range of variation of the input optical power $P_{TX.}$

From the transmission characteristic in Fig. 4 it is evident that the NRZ modulation has more linear characteristic but the saturation zone occurs at a significantly lower input optical power P_{TX}.

Drawing from the graph in Fig. 3, the following special cases may be defined:

– lower boundary case (Min. BER = 1.10^{-12}): for NRZ modulation $P_{TX\ min}$ = –10 dBm, and for RZ modulation $P_{TX\ min}$ = –8 dBm;
– optimal case (lowest possible value for Min. BER): for NRZ modulation $P_{TX\ opt}$ = 2 dBm, and for RZ modulation $P_{TX\ opt}$ = 4 and 13 dBm;
– upper boundary case (Min. BER = 1.10^{-12}): for NRZ modulation $P_{TX\ max}$ = 17 dBm, and for RZ modulation $P_{TX\ max}$ = 18 dBm.

Table 2 summarizes the values of the measured basic parameters obtained for both for both boundary cases ($P_{TX\ min}$ и $P_{TX\ max}$) and for the optimum value ($P_{TX\ opt}$) of the optical power of the transmitter for NRZ modulation, and Table 3 – for NRZ modulation.

***Table 2.** Experimental results for NRZ modulation*

Parameters	$P_{TX\ min}$ = -10 dBm	$P_{TX\ opt}$ = 2 dBm	$P_{TX\ max}$ = 17 dBm
Power P_{RX}, dBm	-13,603	-5,454	-4,876
Average noise level in single channel, dBm	-80	-83	-84
Average noise level, dBm	-53,5	-54,5	-56,2
Optical rise time, ns	0,283	0,409	0,430
Output OSNR for single channel, dBm	12,03	22,03	23,18
Optical Bandwidth, pm	80	130	240
Level and number of parasitic wavelengths	-	-44,7 dBm x 1	-44 dBm x 2

***Table 3.** Experimental results for RZ modulation*

Parameters	$P_{TX\ min}$ = -8 dBm	$P_{TX\ opt1}$ = 4 dBm	$P_{TX\ opt2}$ = 14 dBm	$P_{TX\ max}$ = 18 dBm
Power P_{RX}, dBm	-4,953	-5,977	-5,094	-5,62
Average noise level in single channel, dBm	-80,23	-82,35	-83,26	-82,96
Average noise level, dBm	-53,50	-55,81	-56,01	-56,13
Optical rise time, ns	0,297	0,308	0,335	0,377
Output OSNR for single channel, dBm	10,77	21,46	23,02	22,87
Optical Bandwidth, pm	80	150	200	290
Level and number of parasitic wavelengths	-	-45,39 x 1	-44,09 x 2	-

Since one of the main objectives of the presented model is to determine the optimal solution – the optimum optical power of the transmitter in function of the value of several parameters, in Table 4 and Fig. 5 are summarized the results of the multiparametric analysis for NRZ modulation and in Table 5 and Fig. 6 – for RZ modulation.

***Table 4.** Multiparametric analysis $Q = f(P_{TX}, l)$ for NRZ modulation*

Q-factor		Link length (*l*), km		
		400	500	600
P_{TX}, dBm	0	14,858	11,612	10,005
	1	15,499	12,053	10,307
	2	16,324	12,369	10,582
	3	15,617	11,9	10,111
	4	14,709	11,492	9,978
	6	14,577	11,479	9,876

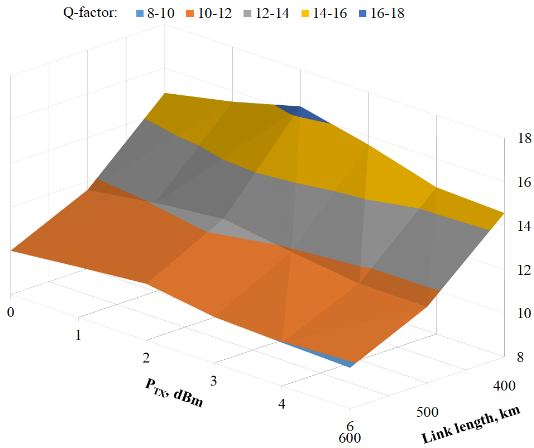

***Fig. 5.** Graphical dependence of Q-factor from P_{TX} and line length l for NRZ modulation*

***Table 5.** Multiparametric analysis $Q = f(P_{TX}, l)$ for RZ modulation*

Q-factor		Link length (*l*), km		
		400	500	600
P_{TX}, dBm	0	14,858	11,612	10,005
	2	16,324	12,369	10,582
	4	14,709	11,492	9,978
	8	28,954	22,443	16,173
	12	30,347	23,494	17,087
	13	29,84	24,615	17,184
	14	29,438	23,876	17,383
	16	20,228	17,344	13,354

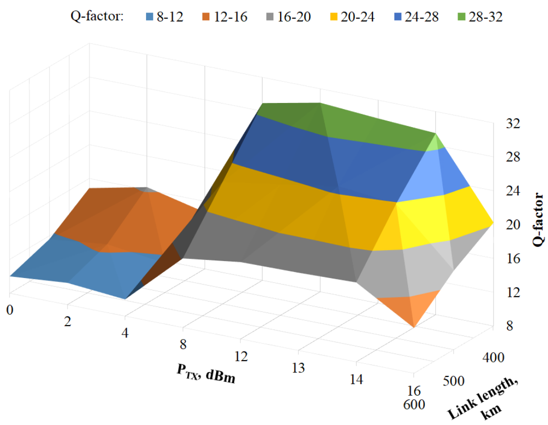

***Fig. 6.** Graphical dependence of Q-factor from P_{TX} and line length l for RZ modulation*

From the graphical dependencies, the maximum Q-factor is determined: for NRZ modulation Q_{max} = 16,324 at the optical line length 400 km and P_{TX} = 2 dBm, and for RZ modulation Q_{max} = 30,347 at the optical line length 400 km and P_{TX} = 12 dBm.

CONCLUSION

The developed model and algorithm offer a convenient and easy analysis and solving of optimization tasks in designing, planning and analyzing the behavior of optical networks with spectral multiplexing.

The use of RZ modulation provides better signal parameters – a minimum BER value and a maximum Q-factor for a wide range of optical transmitter power, compared to the use of NRZ modulation.

Regardless of the better parameters, using RZ modulation results in worse time and spectral characteristics – a higher level of intersymbol interference and wider spectra with higher level of sideband lobes than NRZ modulation.

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