Influence of Optical Fiber Dispersion on Mamyshev Type Regenerator Performance

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Abstract— In this paper we present results from the study on optical signal regeneration by using Mamyshev type regenerator and its dependence on fiber dispersion. Research is performed using computer simulation software Synopsis OptSim 5.3. Setup of investigated regenerator consists of a high power erbium doped fiber amplifier, highly nonlinear fiber and an optical bandpass filter that is slightly shifted away from the signal central frequency. Signal used for regeneration was an on-off keying return-to-zero code manipulated 40 Gbit/s pulse sequence covered with white noise. The regenerator performance was evaluated by obtaining the regenerated optical signal bit error ratio for different optical filters and fiber dispersion coefficients.

1. OPTICAL SIGNAL REGENERATION

Increasing data rates in fiber optics transmission systems leads to a higher requirements to optical signal quality. This is because signal to noise ratio (SNR) requirements become more stringent for higher baud rate signals to ensure the same bit error ratio (BER) level as for lower baud rates. This statement comes from well-known Shannon's Theorem [1].

Optical signal degrades considerably during propagation in the telecommunications fiber line. It is caused by many factors: fiber attenuation, dispersion (group-velocity dispersion, material dispersion, waveguide and polarization mode dispersion) that broadens the pulses, accumulated amplified spontaneous emission that is a broadband noise source induced mostly by amplifiers and, of course, different nonlinear optical effects [2]. Distortions induced by optical fiber nonlinearity actually can be the most significant and the most difficult avoidable, especially in the high data rate multichannel transmission, used in dense wavelength division multiplexed systems.

Optical amplifiers compensate the fiber losses therefore the amplification may be considered as the first level regeneration of optical signal. But amplifiers also degrade the signal by adding ASE noise and timing jitter [3]. It is acceptable for a single stage amplification but becomes unacceptable for signal transmission over long distances with several amplification stages. Therefore there is a need for regenerators that also perform restoration of the signal shape or so called 2R regenerators (reamplifying and reshaping). Reshaping increases the SNR that in turn lowers the signal BER in such a way improving performance of transmission system.

Most commonly the regeneration of optical signals is performed in the electrical domain by performing opto-electrical conversion. Although this approach limits the maximum data transmission rate due to limitations in the electrical equipment operation speed. Therefore more perspective is the optical signal regeneration completely in the optical domain. Since it is based on some nonlinear optical effect exploitation it takes place without any significant delay because optical fiber nonlinear utterance is almost immediate [4]. From the 2R class very promising are the Mamyshev type regenerators (MTRs). The main advantage is a relatively simple design that consists of booster, highly non-linear fiber (HNLF) and optical filter. Despite of setup simplicity there are a lot of parameters that influence the MTR‘s working regime and therefore overall performance. All the parameters could be divided into several major groups: input signal parameters, HNLF parameters, amplifier and optical filter parameters.

The study is based on the simulations performed with computer software Synopsis OptSim 5.3. It is based on the solving the nonlinear Schrodinger equation using the split step method. Filtering influence to operation of MTR was analyzed by using three different optical filters in the simulation mock-up. Regenerator performance was evaluated by analyzing the regenerated output signal BER depending on type of filter and fiber dispersion. Fiber dispersion is a very important parameter in the regeneration process since it influences the self-phase modulation nonlinear effect. This effect in turn provides the signal quality improvement by ensuring different transfer functions for useful signal and noise. This paper consists of 3 sections. The first section describes the simulation scheme of studied regenerator setup. In the second section the results of simulations are given for three different filters used in the MTR setup. The third section gives conclusions of this research.

2. STUDIED REGENERATOR SETUP

In this section of paper the implemented Mamyshev type regenerator will be described. The simulation and experimental regenerator setup is given in the Fig. 1. Transmitter part generates the optical signal which then needs to be regenerated. Bit pattern generator generates a pseudorandom binary sequence with total number of combinations 2^{31}-1, bitrate 40 Gbps and return to zero (RZ) coding. This signal is used to modulate a continuously emitting laser output light via the Mach-Zehnder optical modulator (MZM). To make the output optical signal noisy the MZM was set to work in non-optimal regime by adjusting the operating voltage point of two Lithium Niobate crystals. Thus the output optical signal gets covered with noise.

The next stage in the setup is the regenerator part. It consists of amplifier that boosts the input signal to power level up to 24 dBm to achieve desired spectral broadening due to SPM in the HNLF. The fiber length is 1 kilometer, attenuation coefficient is 2.5 dB/km at 1550 nm and it's nonlinear coefficient is $10.7\,\mathrm{W}^{-1}\mathrm{km}^{-1}$. After the HNLF follow the optical filter. Three different filters were used with the following transfer functions: Super-Gaussian, raised-cosine and measured real optical filter transfer function. Super-Gaussian and raised-cosine filter central wavelength was set to be equal to the real filter central wavelength 1550.3 nm and different filtering offsets form initial signal wavelength were achieved by using a tunable laser. All filter transfer functions are shown in the Fig. 2 and appropriate pass band widths at −3 dB and −20 dB level are summarized in the Table 1.

Receiver part consists of PIN type photodiode and optical eye pattern oscilloscope that is used to monitor the regenerator output signal BER in this way evaluating the effectiveness of the regenerator.

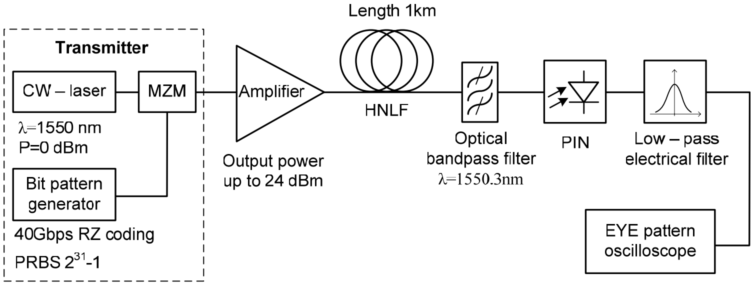


Figure 1: Simulation regenerator setup.

Table 1: Fixed and tunable filter transfer functions and corresponding pass-band widths.

	Super-Gaussian type optical filter	Raised-Cosine type optical filter	Real optical filter
−3 dB level	0.71 nm	1.21 nm	0.68 nm
−20 dB level	1.85 nm	1.82 nm	2.06 nm

3. SIMULATION RESULTS

The first of all it was found that the optimal filter central wavelength shift from signal central wavelength is 0.3 nm. Since SPM induced spectral broadening is symmetrical to both sides from central wavelength this filter shift could be made to both sides. In this research the shifting was performed to higher wavelength (lower frequency) than the initial signal wavelength.

When the filtering offset was chosen the next step was to find the necessary signal power at the input of HNLF to achieve regeneration process. This is very essential since only under certain combinations of filter central wavelength and signal power ensures signal BER improvement. In the Fig. 3 achieved results for all three filters are given. Dashed line is the distorted signal BER at the input and bars represent the regenerator output signal BER. As it can be seen the regenerated signal BER dependence on the amplified signal power shows an occasional character. Mainly this is related to accuracy at which the BER can be determined in the simulation software as well as noise from optical amplifier and receiver that is taken into account in the simulation software.

Therefore it was decided to add fitting function to these results. The second order polynomial function is used for approximation. The dashed square indicates the data area that was used to calculate the approximation function. From results it can be seen that power range that ensures signal BER improvement for Super-Gaussian type filter and real bandpass filter is approximately the same starting from 22.5 dBm up to 23.5 dBm with maximum BER improvement at 23 dBm. Slightly different results were achieved with raised-cosine type filter for which the power range that ensured signal regeneration was broader (22.25–23.8 dBm) and the lowest output signal BER was achieved at 23.4 dBm. Filter with raised-cosine type transfer function also provided an order of magnitude lower output signal BER (1×10^{-9}) compared to other two filters (1×10^{-8}).

Simulation results were also analyzed depending upon fiber dispersion to find out the MTR type regenerator operational changes. The HNLF dispersion coefficient was changed within the range 4–22 ps/nm-km. Subsequently regenerator performance was evaluated by output signal BER compared to input distorted signal BER. Results when three aforementioned filters were used in

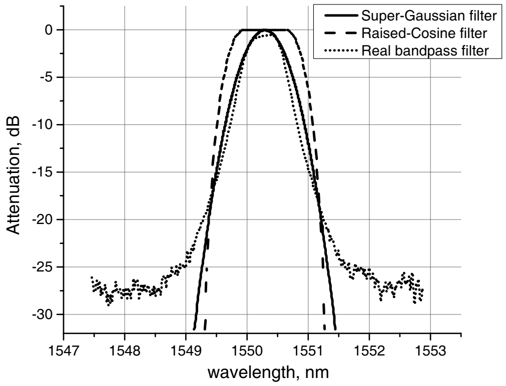
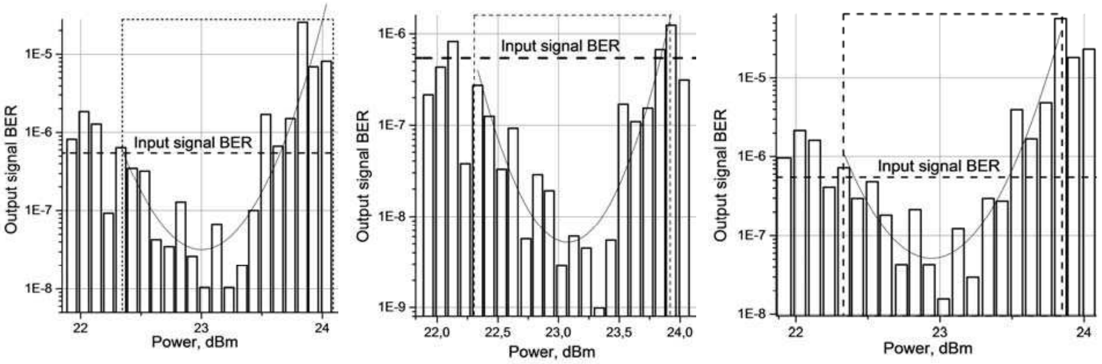
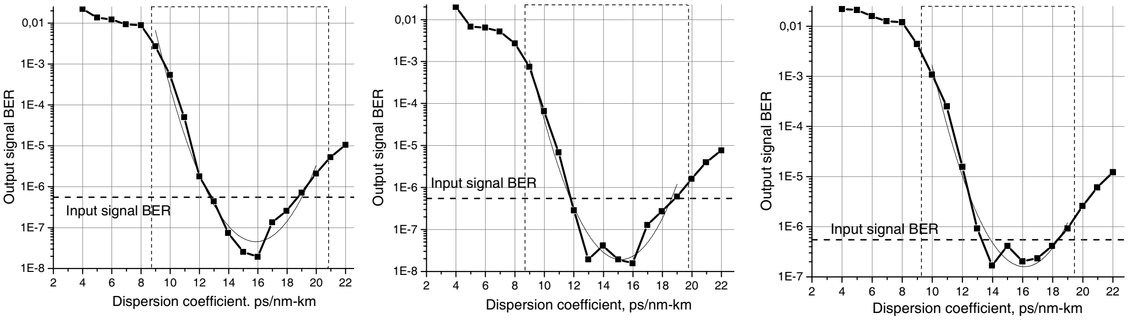


Figure 2: Transfer functions of three different filters: Super-Gaussian, Raised-Cosine and real bandpass optical filter.



Super-Gaussian type filter Raised-Cosine type filter Real bandpass filter

Figure 3: Regenerator output signal BER depending on the amplified signal power.



Super-Gaussian type filter Raised-Cosine type filter Real bandpass filter

Figure 4: Distorted optical signal at the regenerator input (A) and the regenerated output signal (B).

the regenerator setup are given in the Fig. 4. Similarly as in the previous results the BER values were approximated using second order polynomial function.

For all the filters the regenerator performance dependence on the dispersion turned out to be very similar. In all the cases the lowest output signal BER was when the HNLF dispersion coefficient was around 16 ps/nm-km. These results also show that MTR performance is sufficiently sensitive to dispersion since regeneration occurs only for certain range of dispersion coefficient values.

4. CONCLUSIONS

In this paper a tentative MTR setup is described and used in computer simulations to find out filter and fiber dispersion influence to regeneration process. Comparison between three different filters used in the regenerator setup were performed. Better regenerator performance considering the achieved regenerated signal BER was in the case of raised-cosine type filter. Using this filter the initial distorted signal BER (5.49×10^{-7}) was improved up to 1×10^{-9}. This can be explained by taking into account all filter transfer functions given in the Table 1. The raised-cosine filter bandwidth at -3 dB level is twice broader than other filters. It means that transfer function shape is more rectangular. This approves that filter transfer function significantly influences the regeneration process.

The study of dispersion influence to MTR operation revealed that the regenerator performance depends directly on the fiber dispersion coefficient. Only for certain range of dispersion coefficients the output signal was regenerated and its BER was lower than the input signal BER. Whereas the analyzed filter transfer functions showed quite similar performance depending on the HNLF dispersion.

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