Conversion of 40 Gbit/s RZ-OOK to NRZ-OOK with a Single Uniform Fibre Bragg Grating

O. Ozolins, *IEEE member*, V. Bobrovs, *IEEE member,* and G. Ivanovs
Institute of Telecommunications, Riga Technical University, Azenes str. 12-318, LV-1048 Riga, Latvia
oskars.ozolins@rtu.lv

***Abstract* - The format conversion with a single uniform fibre Bragg grating of 40 Gbit/s return to zero on-off keying to non-return to zero on-off keying has been demonstrated numerically for the first time. Error free performance is achieved for uniform fibre Bragg grating with different reflectivity values.**

***Keywords* - fiber Bragg grating; format conversion; all-optical signal processing; return to zero, non-return to zero**

I. Introduction

In recent years fibre optical transmission has gained wide improvement because of every time higher demand of bandwidth due to new services available online and necessity to reduce costs per every bit transmitted [1]. Therefore different modulation formats have been created and employed in optical transmission system depending on the bit rate, network size and system features [2].

On-off keying (OOK) in both return to zero (RZ) and non-return to zero (NRZ) have become the optical modulation format of choice for the most of optical communications systems because of historical circumstances [3]. RZ-OOK format is commonly preferred in transport networks thanks to superior tolerance to inter-symbol interference, polarization mode dispersion, and nonlinear effects [1, 4]. In turn NRZ-OOK format is more spectrally efficient comparing to RZ-OOK and thus is more appropriate for metro and access networks which typically have lower bit-rates and shorter span lengths [1, 5]. Hence interconnections among transport, metro and access networks are necessary. Optical-electrical and electrical-optical conversion degrades system efficiency which is related to increase of time and cost. Due to this, all optical signal processing becomes important [6]. Therefore modulation format conversion will be demanded at the gateways to ensure transparent and efficient interconnection.

All optical format conversion of RZ-OOK to NRZ-OOK formats is a desired function for future ubiquitous transparent. Diverse approaches have been proposed for all-optical format conversion: semiconductor optical amplifier (SOA) and distributed feedback laser (DFB-LD), SOA-loop-mirror, nonlinear optical loop mirror (NOLM) and four-wave mixing (FWM), specially designed silicon micro ring resonator (MRR), SOA/fibre Bragg grating (FBG) [1], [4], [6], [7], [8], [9].

In this paper 40 Gbit/s RZ-OOK to NRZ-OOK format conversion with single uniform FBG filter has been demonstrated numerically for the first time to author knowledge. The good conversion efficiencies are achieved even with low grating reflectivity values.

II. Method of Calculation

OptSim 5.2 simulation program was used to simulate 40 Gbit/s RZ-OOK to NRZ-OOK format conversion. This program is software tool for the design and simulation of optical communication systems at the signal propagation level. Simulation program employs method of calculation that is realized with solving a complex set of differential equations, taking into account electrical and optical noise, linear and nonlinear effects. Two different approaches of calculation are possible: Frequency Domain Split Step (FDSS) and Time

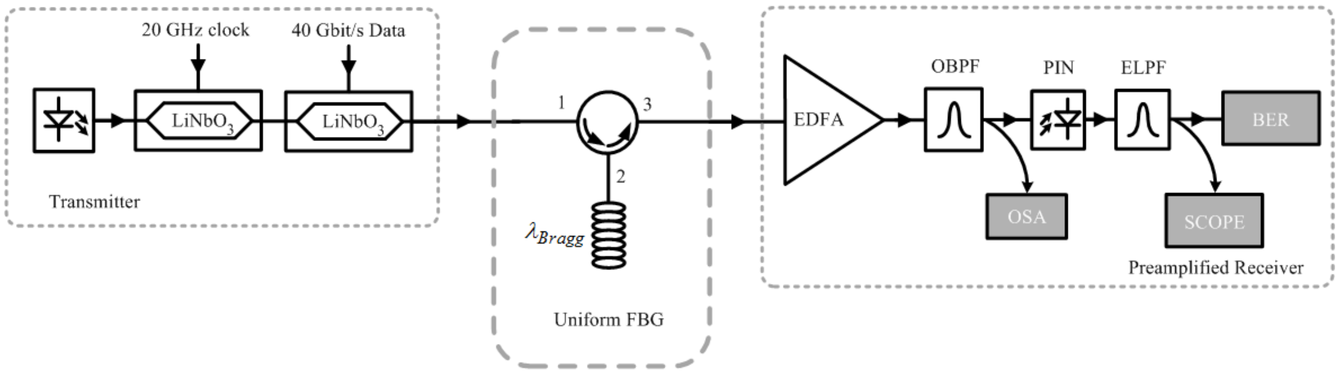

Figure 1. Setup for investigating 40 Gbit/s RZ-OOK to NRZ-OOK format conversion.

Domain Split Step (TDSS) methods. Two methods differ in calculations of linear operator: for FDSS it is done in frequency domain, but for TDSS in the time domain. The first method is simple in to realization, but it could cause multiple errors in simulation. In this research the second method was used, which despite its complexity grants a precise result. This method of calculation is used in all commercial simulation tools to perform the calculation of the fibre propagation equation:

$$\frac{\partial A(t,z)}{\partial z} = \{L + N\}A(t,z) , \qquad (1)$$

where $A(t,z)$-the optical field; L-linear operator that stands for linear effects; N-operator that is responsible for all nonlinear effects. The main idea is to calculate the equation (1) over small spans of fibre Δz by including either linear or nonlinear operator. For instance, on the first span Δz only L operator is considered, on the second – only N operator, on the third – again only L operator [10].

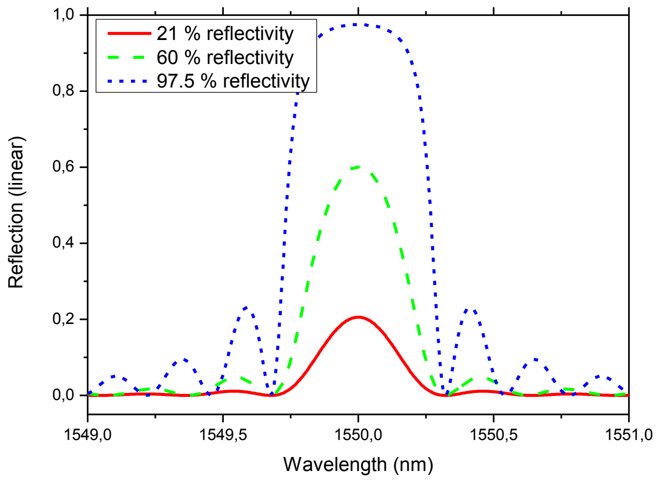

Figure 2. Amplitude transfer function on a linear scale of uniform FBG optical filters with different reflectivity shown in inset.

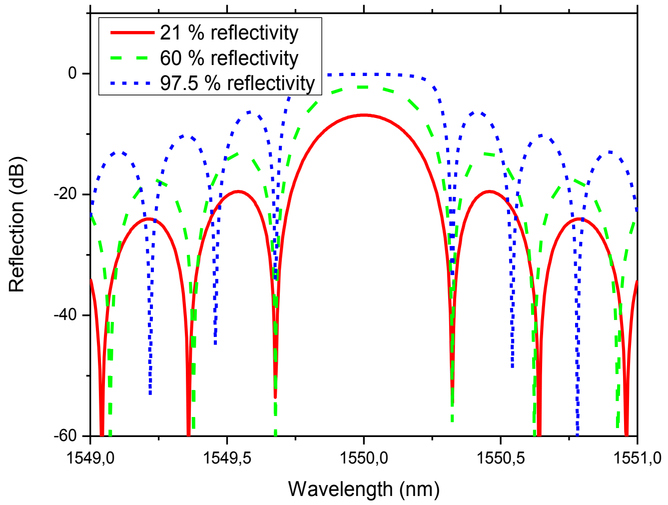

Figure 3. Amplitude transfer function on a logarithmic scale of uniform FBG optical filters with different reflectivity shown in inset.

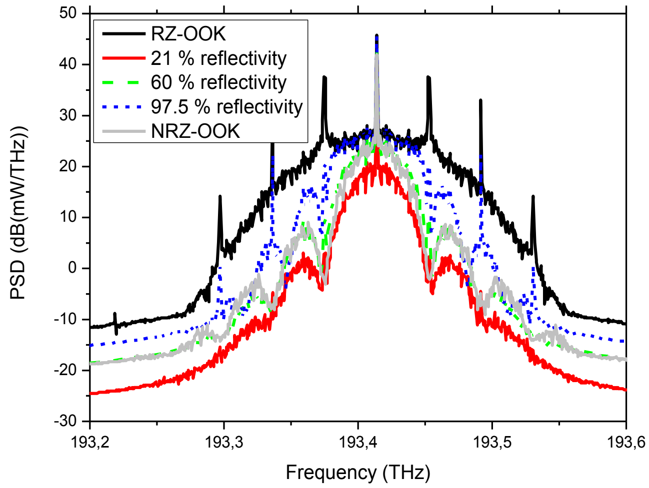

Figure 4. Power spectrum density of the input 33% RZ-OOK, converted NRZ-OOK after different single uniform FBG and generated NRZ-OOK without OBPF.

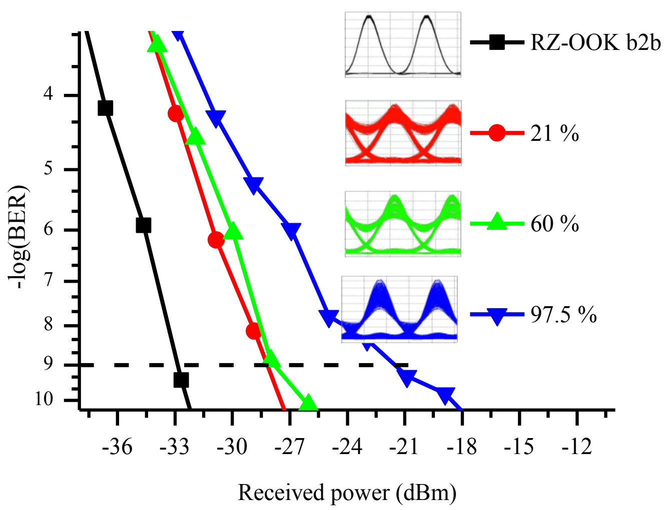

Figure 5. BER as a function of received power for different single uniform FBG for 33% RZ-OOK conversion to NRZ-OOK without additional OBPF. Insets: eye diagrams of back to back 33% RZ-OOK signal and converted NRZ-OOK signals.

Bragg Grating Filters Synthesis (BGFS) 2.6 simulation program was used for calculation of FBG transfer function. In this research three different transfer functions of FBG optical filters reflection spectra were synthesized with uniform apodization profile and 21%, 60% and 97.5% reflectivity values. Transfer Matrix Method is employed in BGFS 2.6 simulation program to simulate different configurations of FBG filters. It is applied to solve the coupled mode equations and to obtain the spectral response of the FBG filter.

As it has been noticed before, two simulation programs were used in research: OptSim 5.2 and BGFS 2.6. Calculated FBG filter parameters were recorded in the data file, which after simple mathematical calculations were used in OptSim 5.2 simulation program to build user defined optical filters.

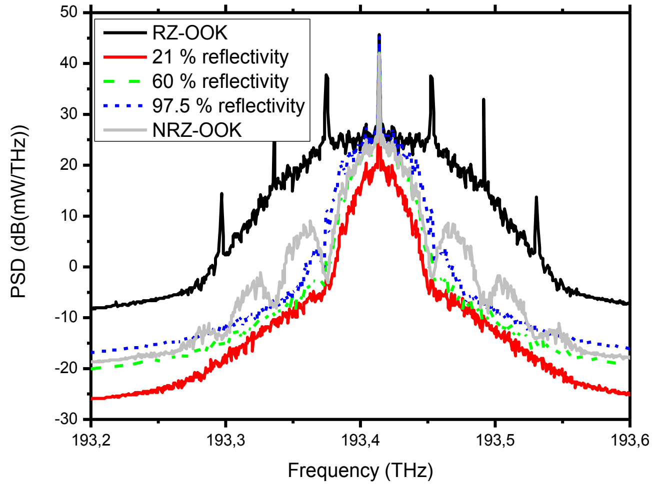

Figure 6. Power spectrum density of the input 33% RZ-OOK, converted NRZ-OOK after different single uniform FBG and generated NRZ-OOK with 45 GHz Gaussian OBPF.

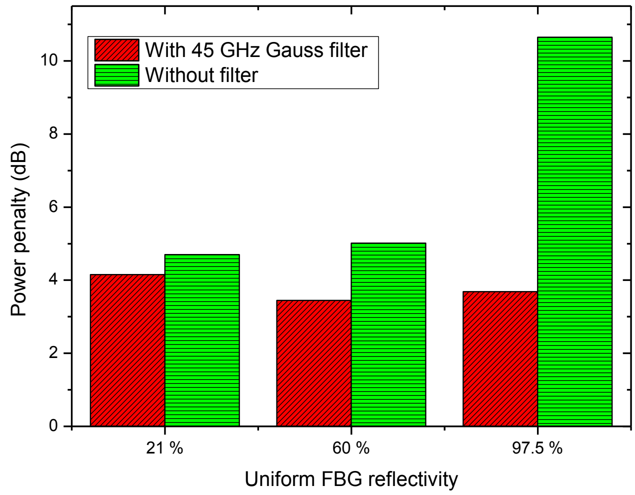

Figure 8. Power penalty (at BER=10^{-9}) induced by a single uniform FBG with different reflectivity for converted NRZ-OOK signal comparing to back to back RZ-OOK signal.

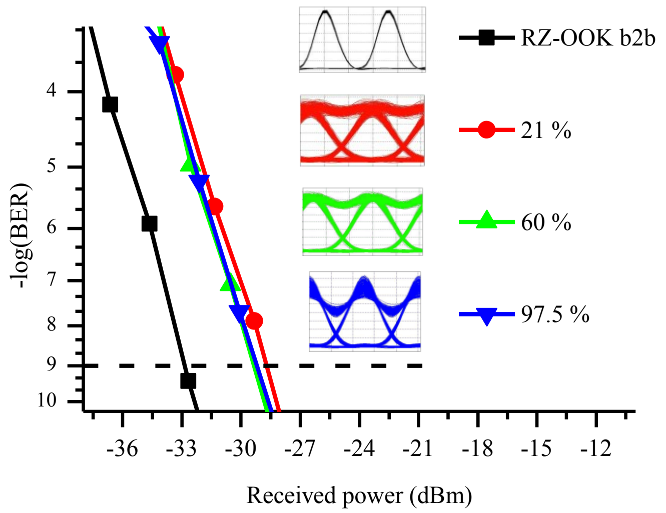

Figure 7. BER as a function of received power for different single uniform FBG for 33% RZ-OOK conversion to NRZ-OOK with 45 GHz Gaussian OBPF. Insets: eye diagrams of back to back 33% RZ-OOK signal and converted NRZ-OOK signals.

III. Simulation Setup and Results

The simulation setup for investigating 40 Gbit/s RZ-OOK to NRZ-OOK format conversion with single uniform FBG filter is illustrated in Fig. 1. The optical transmitter consisted of two LiNbO3 Mach-Zehnder modulators (MZMs) generating 40 Gbit/s RZ-OOK signal. The first MZM, driven by a half clock, was used as pulse carver while the second one was driven by a 40 Gbit/s pseudo random binary sequence (PRBS) with a pattern length of 2^{31}-1. The optical signal was then coupled into the uniform FBG via a first port of optical circulator and collected again at the third port. The signal was detected in a preamplified receiver, which consists of erbium doped fibre amplifier (EDFA), optical band pass filter (OBPF), 45-GHz photodiode, electrical low pass filter (ELPF), optical spectrum analyser (OSA), electrical scope and bit error rate (BER) tester. Employed amplitude transfer functions of FBG filter reflection response are presented in Fig.2 and Fig.3.

Fig. 4 shows the power spectrum density (PSD) of the input 33% RZ-OOK, converted NRZ-OOK after single uniform FBG with 21 %, 60%, 97.5% reflectivity and generated NRZ-OOK. Fig. 5 shows results of BER calculation for 33% RZ-OOK and converted NRZ-OOK after single uniform FBG with 21 %, 60%, 97.5% reflectivity. As one can see from these results that best performance are achieved using uniform FBG with 21 % reflectivity. This can be explained through Gaussian like amplitude transfer function form between first two zeros. In this case conversion was performed without additional OBPF for ripple reduction in eye diagram.

Nevertheless there are amplitude ripples in eye diagrams for all of uniform FBG. To reduce this ripple additional Gaussian OBPF with 45 GHz bandwidth was used. The results of these calculations are shown in Fig. 6 and Fig. 7. Influence of filter to BER performance of converted NRZ-OOK significantly improved in case of single uniform FBG with 97.5 % reflectivity, but still there are ripples in eye diagram. Best conversion in this case was achieved using FBG with 60 % reflectivity. This also could be seen from Fig. 8 in which power penalty (at BER=10^{-9}) induced by a single uniform FBG with different reflectivity for converted NRZ-OOK signal comparing to back to back RZ-OOK signal is shown. Reason for worse performance of FBG with 21 % reflectivity in this case is due to higher insertion loss and additional filter results in over filtering the already converted NRZ-OOK signal.

IV. Conclusion

We have numerically demonstrated a new approach for conversion of 40 Gbit/s RZ-OOK to NRZ-OOK formats using single uniform FBG with different reflectivity values. Best performance is shown in case of FBG with 60 % reflectivity and additional 45 GHz Gaussian OBPF for amplitude ripple reduction in eye diagrams. Also good conversion efficiencies have been achieved with weak FBG.

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