Generation and reception of up to 28Gbit/s optical signals with limited-bandwidth components

Paweł Czyżak*, Paweł Mazurek and Jarosław Piotr Turkiewicz

Institute of Telecommunications, Warsaw University of Technology, Nowowiejska 15/19, 00-665 Warsaw

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Abstract—The utilization of limited-bandwidth electro-optical components in generation and reception of high-speed optical signals up to 28Gbit/s is investigated. The influence of a modulator and photodiode electrical bandwidth on signal quality as well as the influence of chromatic dispersion on a transmitted signal is studied. The results show that the signals can be generated and properly received without any significant loss of chromatic dispersion tolerance in components with a limited-bandwidth. The generation of up to 28Gbit/s signals with a 12.5GHz modulator is demonstrated and evaluated.

In short range optical transmission systems like access/mobile backhaul or LAN, the system cost is a critical factor since it is shared among a limited number of users. One way to decrease the cost of a transmission system is the utilization of directly modulated laser diodes. However, this solution has a serious drawback of limited transmission distance or transmission data rate due to the chirp effect in combination with chromatic dispersion. The chirp effect can be overcome by utilizing modulators like a Mach-Zehnder modulator (MZM) or an electroabsorption modulator (EAM) [1, 2]. An efficient way to decrease the system cost is the use of limited-bandwidth components. The cost of a $LiNbO_3$ optical intensity MZM modulator grows linearly with its bandwidth [3]. The same relation applies to photoreceivers [4]. Thus, the utilization of limited-bandwidth components would significantly reduce the cost of an optical system. However, the resulting signal degradation must be carefully assessed and the influence of transmission impairments such as chromatic dispersion has to be estimated.

In this letter, we investigate the use of limited-bandwidth electro-optical components such as modulators and receivers, in high bit rate transmission at the low system cost, while simultaneously maintaining the desired signal quality. First, the signal quality degradation is studied, caused by a limited-bandwidth of applied components, and further, the influence of chromatic dispersion on the signals generated and received with limited-bandwidth components. Finally, the experimental generation and reception of the up to 28Gbit/s optical signals using limited-bandwidth components is shown.

Figure 1 shows the calculated power penalty at BER=10^{-9} for the MZM and EAM in the function of transmitter and receiver bandwidths normalized to the bit rate. All simulations have been conducted in VPItransmissionMaker 8.5. The extinction ratio (ER) of the MZM was set to 30 dB and for EAM to 10 dB, as typical values for those components.

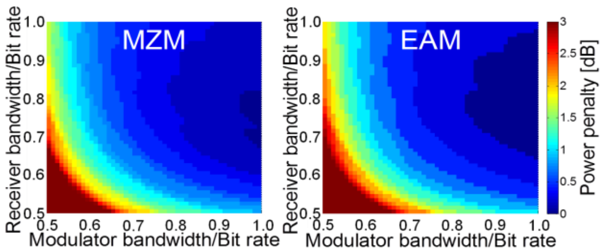

Fig. 1. Power penalty at BER=10^{-9} for different modulator types in the function of a transmitter and receiver normalized bandwidth.

It can be seen in Fig.1 that a relatively small power penalty of 1dB can be expected when both the modulator and receiver bandwidths are limited to 0.65 of the bit rate or when the modulator bandwidth is equal to the bit rate and the receiver bandwidth is drastically reduced to half of the bit rate. On the other hand, keeping the receiver bandwidth equal to the bit rate, one can decrease the MZM bandwidth to 0.55 of the bit rate and EAM bandwidth to 0.6 of the bit rate and maintain the power penalty of 1dB. Furthermore, it can be seen that the MZM performs slightly better than the EAM. For example, when both the modulator and the receiver bandwidths are limited to 0.6 of the bit rate, systems using the MZM suffer from a power penalty of 1.5dB, while those using the EAM suffer from a power penalty of 2dB.

Further, the impact of chromatic dispersion on the signal quality has been studied. In the simulations, limited-bandwidth signals propagated in an optical fiber with a variable dispersion value. In the receiver, the power penalty was calculated. All other propagation effects such as attenuation, polarization mode dispersion

* E-mail: P.Czyzak@stud.elka.pw.edu.pl

and nonlinear effects were not included due to their irrelevance in these particular studies.

Figure 2 presents the power penalty for amplitude modulated 25 Gbit/s signals related to chromatic dispersion, for different bandwidths of the modulator (Mod) and receiver (Rec), for the MZM and the EAM modulator. Each component's bandwidth is normalized to the signal bit rate.

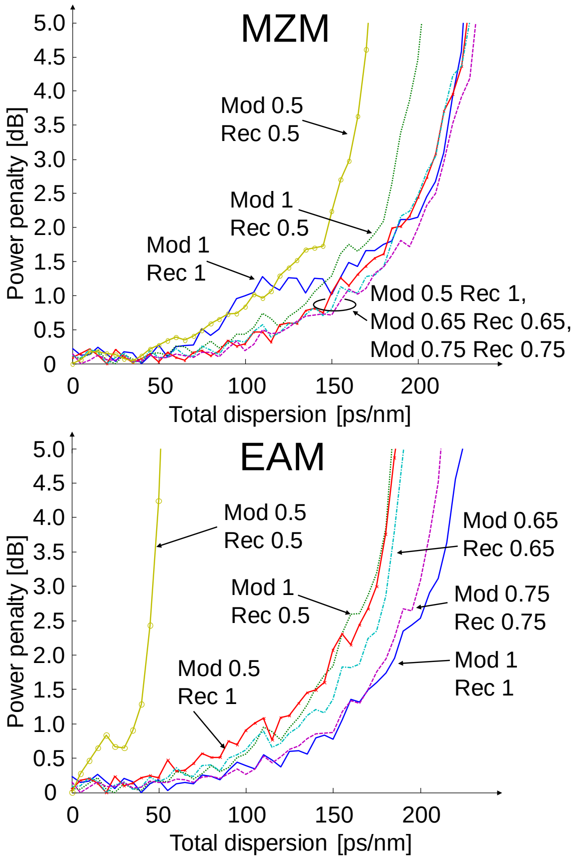

Fig. 2. Power penalty for different dispersion values and modulator/receiver bandwidths and different modulator types; bit rate 25Gbit/s.

It can be seen in Fig. 2 that, generally, the signals generated in the MZM show about 10% better performance regarding the tolerance to chromatic dispersion than those generated in the EAM. The MZM generated signals experience a smaller power penalty due to the higher value of ER. The worst performance was achieved where both the modulator and photoreceiver bandwidths were equal to half of the bit rate {Mod 0.5, Rec 0.5}. In the case of the MZM no large differences can be seen between the performance of systems with these combinations of components' bandwidths: {Mod 1, Rec 1}, {Mod 0.75, Rec 0.75}, {Mod 0.65, Rec 0.65} and {Mod 0.5, Rec 1}. In the case of the EAM, the combinations: {Mod 1, Rec 1} and {Mod 0.75, Rec 0.75} show similar results.

While using the MZM, the combination {Mod 0.5, Rec 1} performs better than {Mod 1, Rec 0.5}. The influence of chromatic dispersion increases with the signal bandwidth, so limiting the bandwidth of the modulator reduces the signal degradation. Therefore it is advantageous to limit the bandwidth of an optical modulator than a photo-receiver. Moreover, modulators are more expensive than photo-receivers [3-4]. Hence, greater cost savings can be achieved by utilization of limited-bandwidth modulators.

Taking into account the better performance of signals generated in the MZM, an experimental system was built, utilizing the MZM and various photodiodes with different bandwidths (Fig. 3).

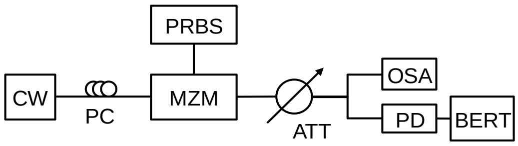

Fig. 3. The experimental setup.

The setup consisted of a continuous wave (CW) laser at 1550nm. The CW signal was modulated with a pseudo random bit sequence (PRBS) of the length $2^{31} – 1$. The MZM was connected to the laser using a Polarization Controller (PC) to provide polarization state alignment. The used modulator was a commercially available component with an electrical bandwidth of 12.5GHz and a static extinction ratio of 35dB [5]. The power of the signal was measured with an optical spectrum analyzer (OSA). The receiver consisted of a photodetector (PD) connected to a Bit Error Rate Tester (BERT). By adjusting the variable attenuator (ATT), different levels of the signal power at the PD were obtained. The measurements were conducted using two available PDs: a 9.5GHz photodiode in combination with a transimpedance amplifier (TIA), and a 50GHz PIN photodiode. The 50GHz PD was applied due to the lack of a 25GHz PD. The 9.5GHz PD had a responsivity of 0.95A/W at 1550nm and including the TIA, a gain of 450V/A. The 50GHz PIN photodiode had a responsivity of 0.65A/W at 1550nm.

The results of the conducted BER measurements are shown in **Błąd! Nie można odnaleźć źródła odwołania.**. The 10Gbit/s signal was used as a reference signal. In all measurments, BER $<10^{-9}$ has been measured. For the reception with the 9.5GHz PD, the power penalty at BER=10^{-9} is 8.3dB. Such a large penalty is atributed to significant signal degradation, Fig. 5. Nevertheless, the signal sensitivity was about -10dBm. Taking into account a typical tranmitter output power of 0 dBm and an attenaution value of 0.2dB/km at 1550nm, the transmission reach of approximately 50km is viable, which is significantly longer that the dispersion compensation free transmission distance, estimated to be about 6km based on Fig. 2. The results of BER measurements taken with the 50GHz PD for 10Gbit/s, 25Gbit/s and 28Gbit/s signals, were very similar to each other and it was possible to achieve a 28Gbit/s data rate, despite the limited 12.5GHz bandwidth of the modulator. The power penalty at BER=10^{-9} for 25/28Gbit/s was ~1dB.

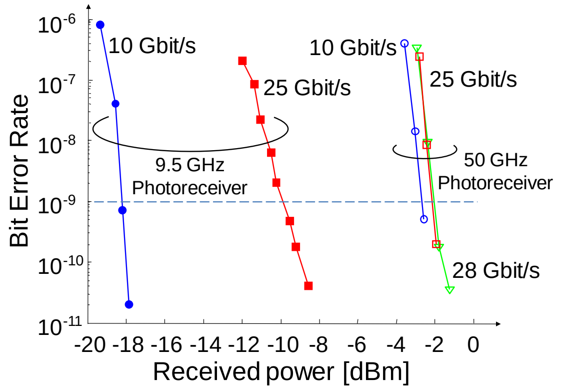

Fig. 4. BER in the function of the received signal power, for the 9.5GHz and 50GHz photoreceiver.

Figure 5 shows the eye diagrams of 10Gbit/s and 25Gbit/s signals received with a 9.5GHz photodiode. The eye diagram of a 25Gbit/s signal has a small eye opening, but it is clear inside and can be properly received, as shown in the BER measurements, Fig. 4. Data rates higher than 25Gbit/s could not be reached with the 9.5GHz PD. Therefore this solution can only by applied for very short transmission links of 25Gbit/s in the range of a few kilometers. The advantage here is the utilization of 10Gbit/s components.

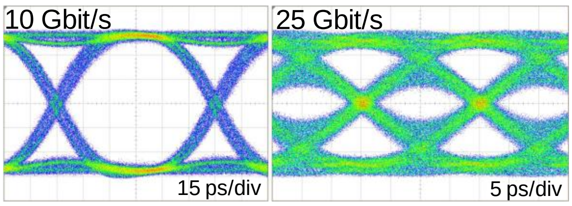

Fig. 5. Eye diagrams of the signals received with the 9.5GHz photodiode.

Figure 6 shows the eye diagrams of the signals received with a 50GHz photodiode. All eye diagrams, i.e. 10Gbit/s, 25Gbit/s, 28Gbit/s and 40Gbit/s show clear signals with a large eye opening with ER values of 14.0dB, 13.1dB, 13.2dB and 11.9dB, respectively. The clear 40Gbit/s eye diagram indicates that even 40Gbit/s signals can be generated in a 12.5GHz modulator and properly received. The solution based on a limited bandwidth modulator and a full photoreceiver bandwidth, allows the transmission of signals up to 28Gbit/s with excellent signal quality. The preliminary results also indicate the possibility of generation and reception of 40Gbit/s signals, however with the signal being distorted. This solution can be applied in the systems where the transmission range will be limited to about 10km at 28Gbit/s.

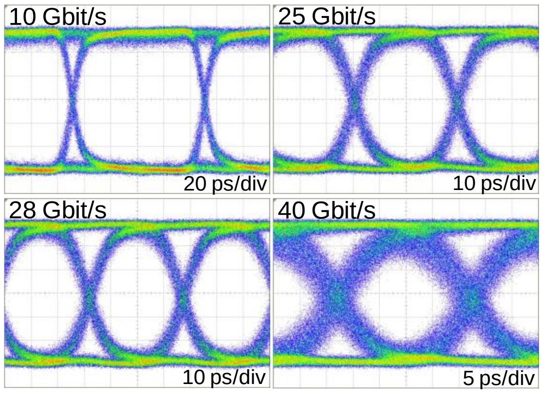

Fig. 6. Eye diagrams of the signals received with the 50GHz photodiode.

In this letter, the possibility of generating high speed signals using limited-bandwidth electro-optical components such asmodualtors and photodetectors is investigated for data rates up to 28Gbit/s. The conducted studies have shown that the component bandwidth can be decreased to 0.65 of the bit rate, without significantly affecting the signal quality. The Mach-Zehnder modulator showed better performance than the electroabsorption modulator, attributed to its higher extinction ratio. Moreover, the use of a limited-bandwidth modulator is more advantageous than the use of a limited-bandwidth photodetector. It was demonstrated in the experiments that a 12.5GHz modulator can be used to generate up to 25Gbit/s signals which can be received with a 9.5GHz PD with a BER < 10^{-10}. The application of a PD with a bandwidth higher than the signal bit rate resulted in better signal quality. The presented results show that limited-bandwidth components can be succesfully applied in optical tranmission systems.

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