Experimental assessment of a Praseodymium Doped Fiber Amplifier (PDFA) for amplifier applications in the second telecommunication window

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We have investigated the system performance of an experimental Praseodymium Doped Fiber Amplifier in an optical transmission system operating at 1.3 µm. Experimental evaluation of the PDFA, based on Bit Error Rate (BER) measurements, is presented for the PDFA used as a booster amplifier, configured in a copropagating scheme, as a function of both wavelength and optical input power. The performance is analyzed for both NRZ and RZ modulation format at a bitrate of 10 Gbit/s. Experimental analysis of the polarization sensitivity and saturation behavior of the PDFA is also presented.

Introduction

In metro networks, where data in the 1.3 μm regime can coexist with regular telecommunication services at 1.5 μm, amplification is needed to overcome fiber and optical add/drop multiplexer losses. In this window Semiconductor Optical Amplifiers (SOA), Raman Amplifiers and Praseodymium-Doped Fiber Amplifiers (PDFA) are good candidates for compensation of these losses [1]. Continuous wave operation of a PDFA based on commercially available modules has been characterized and modeled in [2]. In this paper we present the experimental assessment of the application of PDFAs in a 10 Gbit/s environment for both NRZ and RZ modulation format.

Experimental Setup

The experimental configuration is shown in Fig.1. The CW light from the HP 8167B tunable laser is amplified by an SOA (Philips CQF 882/e SN9) and modulated by a $LiNbO_3$ external modulator, electrically driven by a $2^{31}-1$ NRZ PRBS generator. Directly after the SOA, in the case of NRZ, a tunable optical bandpass filter with a 3 dB bandwidth of 1 nm is used to reduce the ASE noise from the amplifier. The optical input level of the Praseodymium Doped Fiber Amplifier (PDFA), is adjusted by the variable optical attenuator (HP 8156A). At the receiver end, a tunable optical bandpass filter with a 3 dB bandwidth of 1 nm is used to reduce the ASE of the PDFA. In the NRZ experiments a 10 Gbit/s NRZ receiver (NEL) is used. Bit Error Rate (BER) measurements were performed by comparing the detected bits to the transmitted bits as a function of received power, adjusted by a second variable optical attenuator (HP 8157A).
In Fig.1 the adjusted setup for the RZ experiments is also shown. The 10 GHz optical pulse stream is generated by an external-cavity tunable mode-locked laser. The wavelength of the pulse laser can be tuned over more than 30 nm and the generated soliton shaped optical pulses have a pulsewidth of less than 4 ps (FWHM). The same transmitter

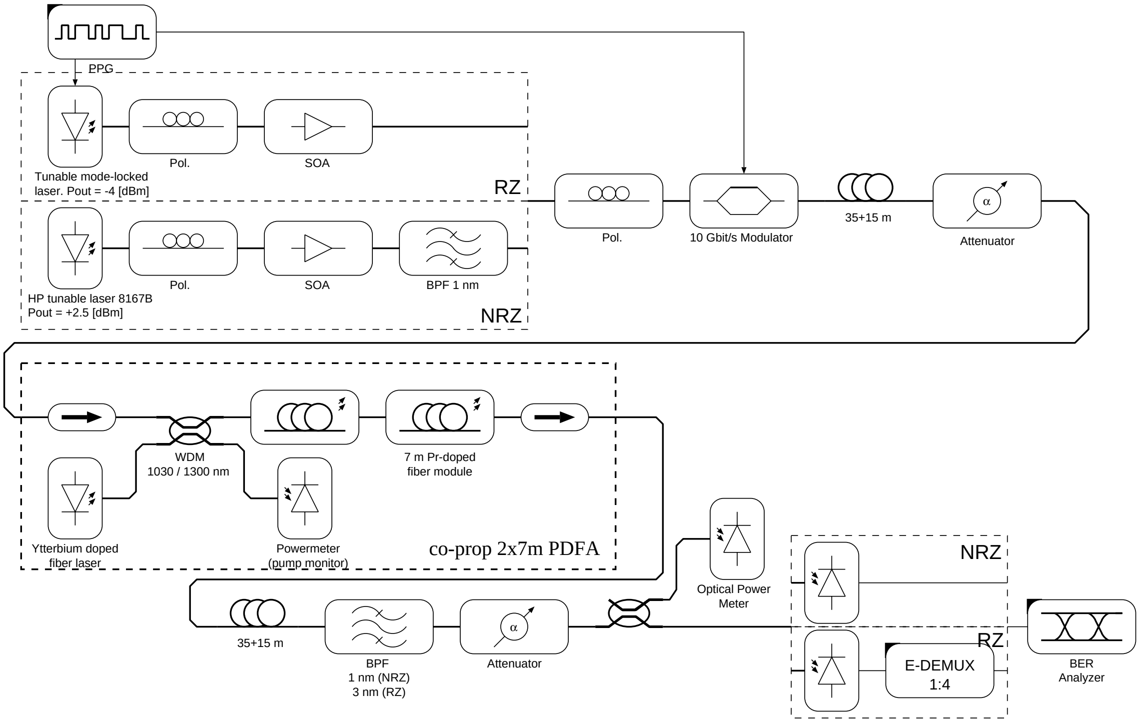

Figure 1: Experimental setup for performance assessment of PDFA in copropagating configuration.

configuration is used, but without the 1 nm tunable optical bandpass filter which would broaden the pulses. At the receiver end, a 3 nm tunable optical bandpass filter is used to reduce the ASE of the PDFA and SOA. For the RZ experiments a custom 10 Gbit/s RZ receiver, with a 1:4 Electronic Time Domain Demultiplexer is used.

Praseodymium Doped Fiber Amplifier

The configuration of the amplifier under investigation is also shown in Fig.1. In this paper we focus only on a copropagating pump configuration. An ytterbium fiber laser operating at 1030 nm is used as pump source (300 mW pump power). The signal and pump powers are combined in a 1030/1300 WDM, which is connected to the praseodymium-doped fiber modules (NEL). Each praseodymium-doped fiber module contains 7 m, 1000 ppm Pr doped In-based fluoride fiber between the two silica fiber pigtails. In the configuration and optical input powers under investigation the effective fiber-to-fiber amplification is in the order of 10 dB depending on wavelength, optical input power and modulation format.

Results and Discussion

The results of the BER-measurements at 1300 nm of the 10 Gbit/s NRZ and RZ setup are shown in Fig.2. The BER-performance of the PDFA is evaluated at three different input levels (-5 dBm, -10 dBm and -15 dBm) and for four different wavelengths (1290 nm, 1300 nm, 1310 nm and 1320 nm). The performance of the PDFA for 10 Gbit/s NRZ and

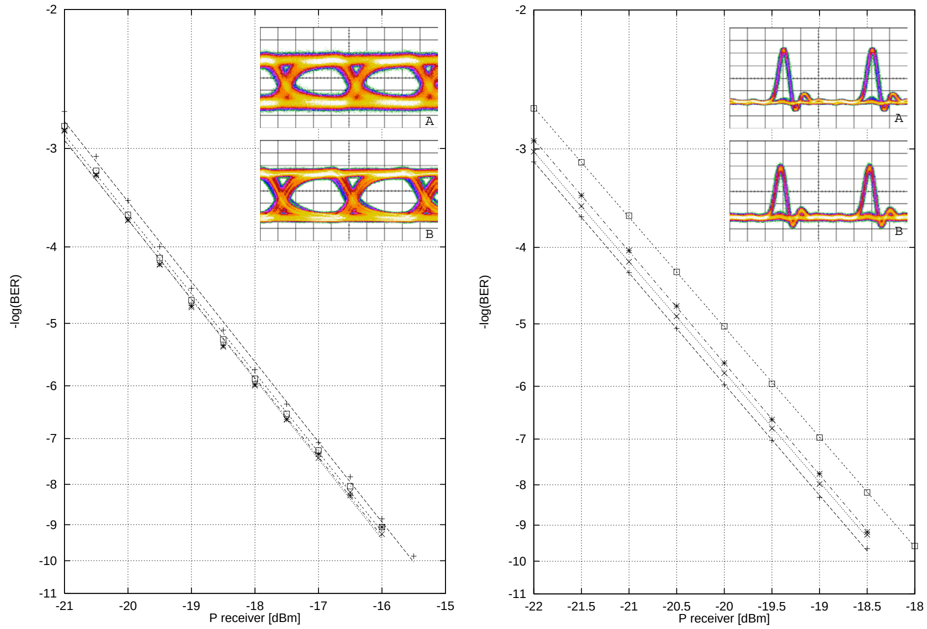

Figure 2: BER measurements for 10 Gbit/s NRZ (left) and RZ (right) at 1300 nm. (+) B2B, (X) P = -5 [dBm], (*) P = -10 [dBm] and (❑) P = -15 [dBm].

RZ is independent (less than 0.2 dB) of the wavelengths investigated. In all experiments the PDFA is used as a booster amplifier and is saturated for the investigated input power levels.

The polarization sensitivity of the PDFA is analyzed by adjusting a polarization controller in front of the PDFA and optimize the polarization for maximum and minimum received optical power levels. The difference found is less than 0.2 dB and the found difference in BER corresponds to this difference in optical power. Repeating this experiment without PDFA results in the same polarization sensitivity of slightly less than 0.2 dB, therefore the polarization sensitivity of the PDFA is negligible compared to the other components in the experimental setup.

The BER graph for the NRZ measurements (Fig.2 left) shows that the back-to-back (B2B) curve is slightly worse (0.2 dB) than the curves with PDFA. The inset with the corresponding eye-diagrams ((A) before, (B) after amplification) indicates a noise reduction of the signal after the PDFA. This means that the optical signal to noise ratio (OSNR) of the signal is enhanced due to the reduced ASE- and beat-noise components in the signalband in the saturated amplifier. Further decrease in input power levels at the input of the PDFA will degrade the performance, which is obvious because the amplifier adds more noise to the signal as the signal becomes weaker. The BER graph for the RZ measurements (right) indicate a small penalty, up to 0.5 dB for the smallest optical input power (-15 dBm). In addition, we compared the saturation behavior of the PDFA with an SOA which is not optimized for booster application. The bitpatterns and eye-diagrams are shown in Fig.3 (Input power in all cases -5 dBm). In contrast to the large pattern effects in an SOA, no pattern effects are present in the PDFA. The timeconstants in an SOA are in the same order of magnitude as the bittime, resulting in large pattern effects since the recovery of gain occurs within a few bitperiods. In contrast to the SOA, in the PDFA the product of

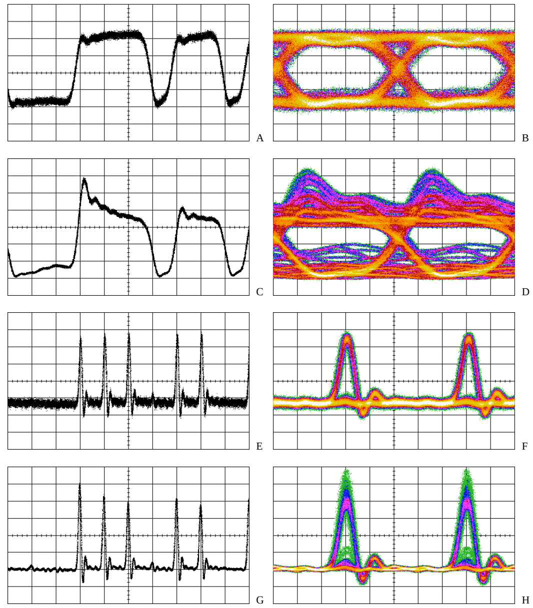

Figure 3: Pattern- en Eye-diagrams for PDFA (A,B,E and F) and SOA (C,D,G and H).

timeconstant and length is much larger and is determined, among others, by the pump ground state absorption (the process of pumping the electrons into the excited state). A high level of population inversion cannot be achieved over the entire active fiber. Consequently, the effective gain will be averaged over a large number of bits. The absence of pattern effect is a desired feature in booster amplifiers where input signal levels are high.

Conclusions

We experimentally investigated the performance of a PDFA used as a booster amplifier in a copropagating configuration based on BER measurements. We analyzed both 10 Gbit/s NRZ and RZ modulation formats for different wavelengths and optical input powers. The high input powers saturate the PDFA and, in case of NRZ, slightly improve the OSNR of the data signal. The polarization sensitivity of the PDFA is negligible in the presence of other components in the setup. Saturation of the PDFA does not result in pattern dependent behavior. Compared to an SOA, a PDFA has a large product of timeconstant and length which results in the averaging of the effective gain over a large number of bits.

Acknowledgment

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