All-optical 1310-to-1550 nm wavelength conversion including transmission over two fibre links

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We demonstrate all-optical 1310-to-1550 nm wavelength conversion utilizing nonlinear polarization rotation in a semiconductor optical amplifier in between two standard single mode fibre based transmission links. Error-free operation at 10 Gbit/s is shown.

Introduction

A number of access-metro schemes utilizing simultaneously 1310 nm and 1550 nm transmission window have been proposed [1]. To avoid optical-electrical-optical conversions and to realize all-optical networking the 1310 nm data stream has to be translated all-optically into the 1550 nm wavelength domain. Several 1310-to-1550 nm wavelengths converters [2-5] have been reported. Another promising candidate to achieve all optical 1310-to-1550 nm wavelength conversion is nonlinear polarization rotation in a semiconductor optical amplifier [6]. Although, nonlinear polarization rotation in the SOA was applied previously also for in-band wavelength conversion [7] the transmission feasibility of converted signals was not verified. Moreover, the transmission feasibility was not verified in the case of other ultra wide-band wavelength conversion technologies [2-6].

In this paper, we report all-optical 1310-to-1550 nm wavelength conversion based on nonlinear polarization rotation in an SOA in between two transmission links. As a transmission fibre we used two standard single mode fibre (SSMF) based spans. We demonstrate that error-free wavelength conversion from 1310-to-1550 nm can be realized at bit rate 10 Gbit/s by using a single SOA after 25 km transmission over SSMF and the converted signals can be further transmitted error-free over the next fibre span, namely 100 km of SSMF with dispersion compensation modules.

Experimental setup

Fig. 1 shows the experimental setup. We generate a 10 Gbit/s non return-to-zero (NRZ) signal by modulating a continuous wave (CW) signal at 1310 nm in an external Mach-Zehnder modulator with the pseudorandom bit sequence (PRBS) of length 2^{31}-1. The modulated signal is fed into a 25 km long SSMF transmission line. The SSMF is the most deployed nowadays fibre [8]. The SSMF is characterized in the 1310 nm transmission window by virtual absence of dispersion related penalties, (zero dispersion wavelength between 1300 and 1324 nm), and attenuation lower than 0.5 dB/km [9]. The transmission reach of access systems is specified to be less than 20 km [1]. After first transmission line, signal enters an all-optical 1310-to-1550 nm wavelength converter. The 1310 nm input signal average power is set to -8 dBm. As a wavelength converter we use an all-optical wavelength converter based on nonlinear polarization rotation in an SOA as described in [6]. The input signal polarization state is adjusted by a polarization controller. An optical band-pass filter (OBP) reduces amplified spontaneous emission noise (ASE) and prevents a switching SOA from unwanted saturation.

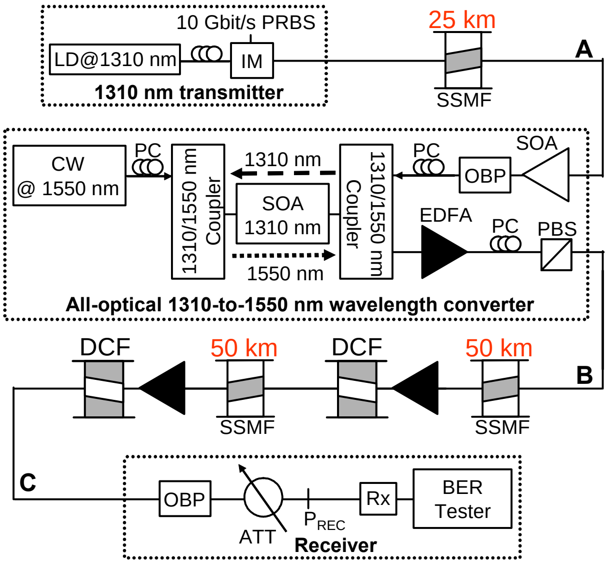

Fig. 1 Experimental setup

Next, the 1310 nm NRZ signal passes through a 1310/1550 nm coupler and finally enters a 1310 nm SOA. The multi-quantum well SOA employed has 400 mA driving current. The 1550 nm continuous wave (CW) laser power is set at 7.0 dBm. The polarization of a 1550 nm CW light is adjusted by a polarization controller to be approximately 45° to the orientation of the SOA polarization axes. Then, the 1550 nm CW signal passes through a 1310/1550 nm coupler and is feed into the 1310 nm switching SOA. The SOA is generally a birefringent device [10]. The injected 1310 nm light introduces additional birefringence in the SOA via carrier density changes [10]. This causes the transverse magnetic (TM) and the transverse electric (TE) modes of the signals traveling through the SOA to experience a different refractive index, also in the transparency region of the SOA. Therefore, the 1550 nm signal at the SOA output has a changed state of polarization with respect to the 1550 nm signal without any 1310 nm signal present. After passing through the SOA, the 1550 nm signal is amplified in an erbium-doped fibre amplifier (EDFA) to compensate for the losses in the 1310 nm switching SOA and enters a polarization filter formed by a polarization beam splitter (PBS) and a polarization controller. The polarization filter is adjusted in such a way that the 1550 nm signal with the rotated polarization passes through it. The average power of the output 1550 nm signal is set to 0 dBm and optical signal-to-noise ratio (OSNR) is measured to be 28 dB. Although, no ASE noise is added to the 1550 nm CW signal in the 1310 nm switching SOA the following EDFA reduces OSNR value of the 1550 nm signal. This OSNR reduction can be avoided by applying a strong CW signals. However, limitation here is a power handling capability of the 1310 nm switching SOA. After passing through the polarization filter, the 1550 nm signal enters a second transmission line. The second transmission line consists of two 50 km long SSMF spans, two dispersion compensation fibre modules and two EDFAs to compensate for losses in the transmission fibre. The SSMF is characterized in the 1550 nm transmission window by chromatic dispersion lower than 17 ps/nm*km and attenuation lower than 0.4 dB/km [8]. Together, the dispersion compensation fibre modules compensate for 1619 ps/nm. Therefore, full compensation of the accumulated dispersion of 100 km SSMF is achieved. After passing through the second transmission line, the 1550 nm signal is evaluated in a receiver and the bit error rate (BER) tester. The receiver consists of an OBP, a variable attenuator (ATT), and a 10 Gbit/s data receiver in combination with the BER tester.

Results and discussion

Figure 2 presents 10 Gbit/s measured eye diagrams: a 1310 nm signal after 25 km transmission at the wavelength converter input (a), a 1550 nm signal at the wavelength converter output (b), and a 1550 nm signal at the 100 km transmission line output (c), points A, B, and C in Fig. 1 respectively. All eye diagrams show a clear open eye and indicate excellent operation of the wavelength conversion and the transmission. The 1550 nm signals show some asymmetry between rise and fall time, which can be attributed to the slow carrier recovery time of the SOA. Also accumulation of the ASE noise is visible in Fig. 2(b-c). Figure 3 shows optical spectra measured at the indicated points: the wavelength converter input (a), the wavelength converter output (b), and the 100 km transmission line output (c). The input 1310 nm signal has the best OSNR ratio, namely 38 dB. The converted 1550 nm signal has OSNR value 28 dB and the 1550 nm signal after transmission has OSNR equal to 26 dB. The OSNR degradation is caused by the accumulation of ASE noise in the EDFAs applied in the transmission line. This OSNR degradation of the 1550 nm signal leads to the BER degradation. Figure 2 shows the measured BER curves. No BER error floor is observed, which indicates again excellent operation of the wavelength converter. By comparing the 1310 nm input signal with the 1550 nm converted signal we estimate the wavelength conversion power penalty at BER 10^{-9} to be 1.2 dB. By comparing the 1550 nm signal before and after transmission we estimate the transmission power penalty at BER 10^{-9} to be 0.5 dB. By adjusting the polarization state of the 1310 nm input signal we verified polarization sensitivity of the presented wavelength converter. The changes in input polarization affected only the 1550 nm signal output power. The quality of the signal (BER) was polarization independent i.e. polarization dependency lower than 1 dB.

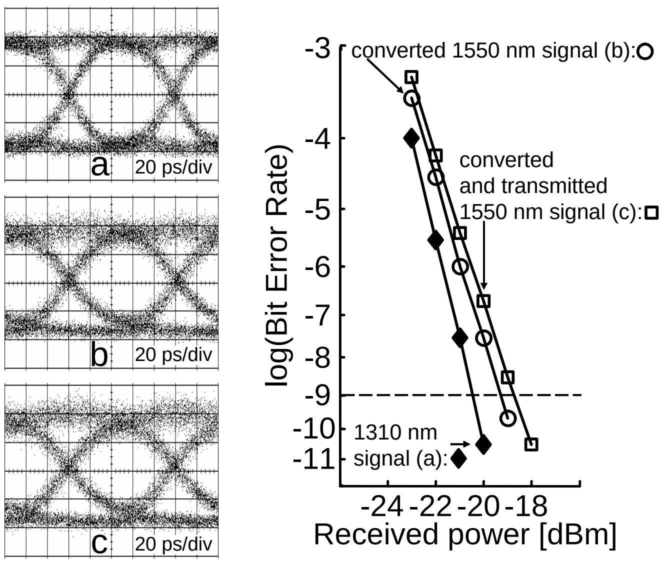

Fig. 2 Results of eye and BER measurements: (a) 1310 nm signal after 25 km transmission ♦, (b) 1550 nm signal after wavelength converter ○, and (c) 1550 nm signal after 100 km transmission □

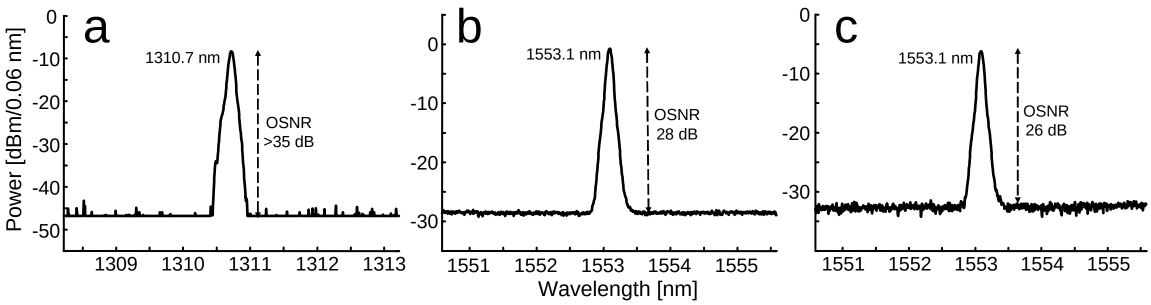

Fig. 3 Measured optical spectra: (a) 1310 nm signal after 25 km transmission, (b) 1550 nm signal after wavelength converter, and (c) 1550 nm signal after 100 km transmission

Conclusions

We have demonstrated 1310-to-1550 nm wavelength conversion in between two standard single mode fibre based transmission links. We achieved error-free wavelength conversion and transmission at 10 Gbit/s. We verified that the wavelength converter based on nonlinear polarization rotation in an SOA can be applied in the transmission systems to overcome optical-electrical-optical conversion at the network nodes interfacing access-metro and core networks. Moreover, the experimental results proofs that the cross-band transmission can be realized using the same type of fibre.

Acknowledgments

This work was supported by The Netherlands Organization for Scientific Research under The NRC Photonics Grant.

References

[1] M. Nakamura, H. Ueda, S. Makino, T. Yokotani, and K. Oshima, “Proposal of networking by PON technologies for full Ethernet services in FTTx”, IEEE J. Lightw. Technol., 2004, 22, (11), pp. 2631-2640

[2] C. Q. Xu, H. Okayama, and M. Kawahara, “Wavelength conversion between the two silica loss windows at 1.31 and 1.55 μm using difference frequency generation”, Electron. Lett., vol. 30, pp. 2168-2169, 1994.

[3] J. P. R. Lacey, G. J. Pendock, and R. S. Tucker, “All-Optical 1300-nm to 1550 nm wavelength conversion using cross-phase modulation in a semiconductor optical amplifier”, IEEE Photon. Technol. Lett., vol. 8, pp. 885-887, 1996.

[4] P. E. Barnsley and P. J. Fiddyment, “Wavelength conversion from 1.3 to 1.55 μm using split contact optical amplifiers”, IEEE Photon. Technol. Lett., vol. 3, pp. 256-258, 1995.

[5] D. N. Maywar, Y. Nakano, and G. P. Agrawal, “1.31-to-1.55 μm wavelength conversion by optically pumping a distributed feedback amplifier”, IEEE Photon. Technol. Lett., vol.12, pp. 858-860, 2000.

[6] J.P. Turkiewicz, G.D. Khoe, and H. de Waardt, “A novel 1310 nm to 1550 nm wavelength converter”, Ninth IEEE/LEOS Benelux Chapter Symposium 2004

[7] M. F. C. Stephens, M. Asghari, R. V. Penty, and I. H. White, “Demonstration of ultrafast all-optical wavelength conversion utilizing birefringence in semiconductor optical amplifier”, IEEE Photo. Technol. Lett., vol.9, pp. 449-451, 1997.

[8] www.corning.com

[9] ITU-T Recommendation G.652

[10] R. J. Manning, A. Antonopoulos, R. Le Roux, and A. E. Kelly, “Experimental measurement of nonlinear polarization rotation in semiconductor optical amplifiers,” Electron. Lett., vol. 37, no. 4, pp. 231-229, February 2001.