Towards High Capacity Transmission in the 1310 nm Wavelength Domain

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*In this paper we evaluate the feasibility to realize low-complexity high capacity transmission in the 1310 nm wavelength domain. The all-semiconductor high capacity n*40 Gbit/s DWDM transmission experiments are presented and the results evaluated. The results of the conducted studies indicate that the 1310 nm wavelength domain has a high potential to support low-complexity and high capacity transmission for applications like the future 400G and 1T Ethernet standard.*

Introduction

Novel transmission and switching technologies are needed to accommodate the ever growing demand for the transmission capacity. The solution to increase capacity of the fibre links or to realize the cost-effective transmission that gets significantly less attention is transmission out of the 1550 nm transmission window. At present, high capacity transmission is exclusively located in the 1550 nm transmission window. By utilization of other transmission windows like the 1310 nm (O-band) or the 1450 nm (E-band) high capacity transmission can be realized and significant cost savings can be achieved. Obviously, due to the higher attenuation and limited performance of the optical amplifiers, the system reach will be limited to the short/medium distances. However, such distances between the electrical switching fabrics are typical in the metropolitan/campus networks and support data and storage center transmission, which is a very fast growing application area for optical transmission technologies. Moreover, those transmission windows can be utilized in parallel to the 1550 nm transmission window and therefore postpone very expensive migration towards systems based on advanced modulation formats or installation of new fibres. The proposed systems can utilize low complexity technologies, giving a very good prospect for component and subsystem integration and finally the low system cost. All that can be accomplished by utilization of the 1310 nm transmission window.

Current applications of the 1310 nm transmission window are limited to the upstream channel in fiber to the home (FTTH) systems as well as a newly developed IEEE 802.3ba Ethernet standard, where the whole 1310 nm transmission window is utilized for only one 100 Gbit/s channel (4×25 Gbit/s) [1]. Several laboratory transmission experiments in the 1310 nm wavelength domain has been presented, e.g. [2-3] and the 1310 nm wavelength domain components are under constant development, e.g. [4-5]. In this paper we present for the first time, the low complexity and high capacity DWDM n×40 Gbit/s over 38 km of SSMF transmission systems in the 1310 nm transmission window utilizing exclusively semiconductor components without any form of dispersion compensation.

Experimental setup

Fig. 1 shows the experimental setup of the cost-effective low-complexity n×40 Gbit/s transmission system. All the components used in the experiments were the packaged and pigtailed devices acquired from the commercial component suppliers. The transmitter consisted of eight continues wavelength (CW) lasers operating at wavelengths: 1311.5 nm, 1312.9 nm, 1314.3 nm, 1315.6 nm, 1317.0 nm, 1318.4 nm, 1319.8 nm and 1321.2 nm, which were denoted I-VIII respectively. The number of the utilized wavelength channels was limited by the available component base, namely the CW lasers. The CW power of all lasers was equalized to match the power of the minimum output power laser. After passing through the polarization controllers all CW signals were combined in a following arrayed waveguide grating (AWG). The AWG channel spacing was equal to 1.4 nm, which corresponds to about 250 GHz at 1310 nm. The uniform spacing wavelength allocation scheme was applied. The average transmitter AWG insertion loss was 3.2 dB and the polarization dependent loss was about 1 dB. After the AWG the signals entered an electro-absorption modulator (EAM). The EAM had the 3dBe RF bandwidth of 39 GHz. In the EAM all signals were modulated simultaneously at the bit rate 40 Gbit/s with the pseudo random bit sequence (PRBS) of length 2^{31}-1 coming from a pattern generator (PG). The utilized EAM was driven with the electrical signal of the voltage swing equal to 2.4 V_{pp} and the DC-bias set to 1.9 V. The settings of the electrical signal remained unchanged during all measurements. Therefore the signal control and adjust circuit was omitted significantly simplifying the system design. The measured extinction ratio of the modulated 40 Gbit/s signals was 8.5 dB.

To at least partially decorrelate the bit patterns of the different wavelength channels a 2.5 km long dispersion shifted fibre (DSF) was used. The DSF had the absolute dispersion value of 42.5 ps/nm and attenuation of 2 dB. To compensate for the losses in the EAM, the DSF and to maximize the transmitter output power a semiconductor optical amplifier (SOA) booster was used. The booster SOA had a nominal gain of 14.0 dB and saturation power of 13.0 dBm. After being simultaneously amplified in the SOA, all signals were injected into the transmission line.

The transmission line was based on the standard single mode fibre (SSMF). The parameters of the transmission link were as follows: the exact length 38.1 km, attenuation at 1310 nm 3.25 dB/km, the zero dispersion wavelength 1316.3 nm, dispersion at 1310 nm 0.281 ps/nm*km and dispersion slope 0.087 ps/nm*km2, which conforms the ITU-T Recommendation G.652. After the transmission link, the transmitted signals entered a DWDM receiver. Please note that no dispersion compensation was applied, neither in the optical or the electrical domain. The DWDM receiver consisted of an SOA, the second AWG and an electro-optical converter.

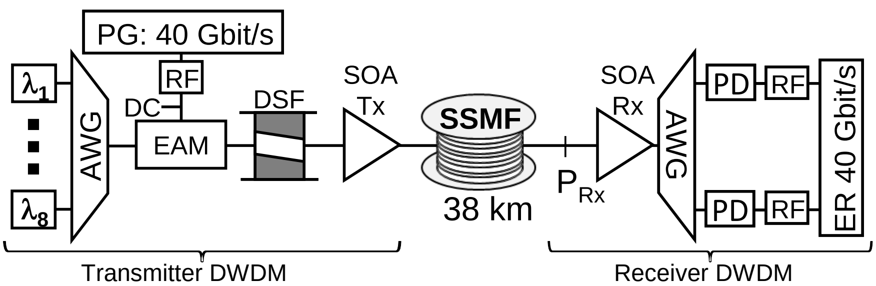

Fig. 1. The experimental setup of 8×40 Gbit/s DWDM in the 1310 nm transmission window

The preamplifying SOA had a nominal gain of 14.0 dB and saturation power of 13.0 dBm. Next, the wavelengths channels were fed into a demultiplexing AWG, which performed the wavelength demultiplexing and the optical noise filtering. The receiver AWG had a slightly higher loss of additional 1.3 dB than the one utilized in the transmitter. Further, the optical signal was converted to the electrical domain in a photodiode in combination with the electrical amplifier. The photodiode had the responsivity of 0.58 A/W at 1310 nm. The following microwave amplifier had the gain of 20 dB. The clock signal was recovered from the received data signal. Subsequently, the data and clock signals were feed into an error detector (ED).

Results and discussion

Fig. 2 shows the optical spectra after the transmitter, the transmission line and the preamplifying SOA. The power level of the signal injected into the transmission line was about -0.6 dBm per channel. After the transmission line the power level dropped to -13.2 dBm. No four-wave mixing products are visible. After the preamplifying SOA the signal reach the level of 2.2 dBm. The optical signal-to-noise ratio (OSNR) dropped from 33 dB after the booster SOA to 30 dB after the preamplifying SOA. Spreading in the optical power level of channels due to the residual polarization sensitivity of the utilized components can be noticed in particular in Fig. 2C.

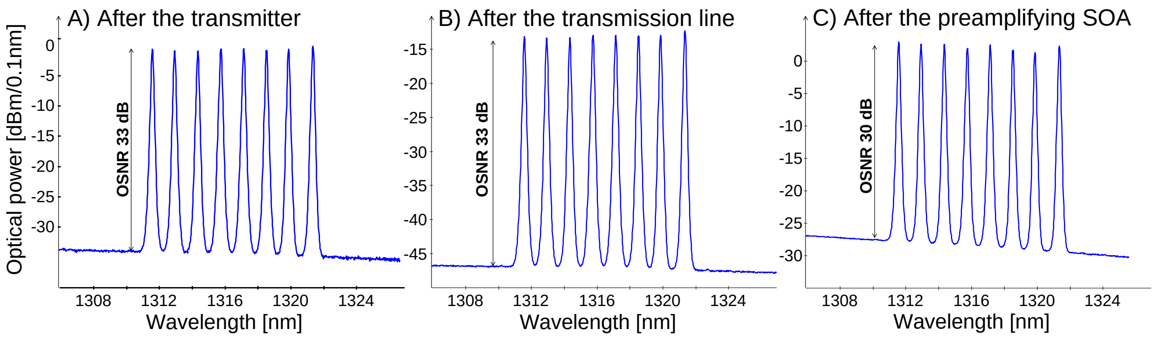

Fig. 2. The captured optical spectra 8×40 Gbit/s DWDM in the 1310 nm wavelength domain

Fig. 3A shows the measured eye diagrams for the channel I and VIII after the transmitter and before the photodiode. All eye diagrams show a clear eye opening and indicate excellent operation of the transmission system. Some signal distortions due to the OSNR degradation and residual saturation effects are visible in the signal after the transmission. Fig. 3B shows the bit error rate (BER) measurements results. No error floor was observed. The average sensitivity in the back-to-back measurements at BER=10-9 was -14.3 dBm and 15.5 dBm for the transmission respectively resulting in the average penalty of the 1.2 dB. The spreading in the system performance is mainly caused by wavelength and polarization depended responsibility of the utilized components like AWG and SOA as well as lack of the active signal control subsystems, i.e. the fixed driving electrical signal was utilized and the polarization control of the signals was not applied. Nevertheless the 1.5 dB spread at BER=10^{-9} is very low taking into account the significant simplification of the system design and therefore the reduced system cost. The total system capacity was limited by the availability of the components. Adding two additional channels will result in the power increase of 1 dB, therefore will not affect the operation of the SOA by driving it into saturation.

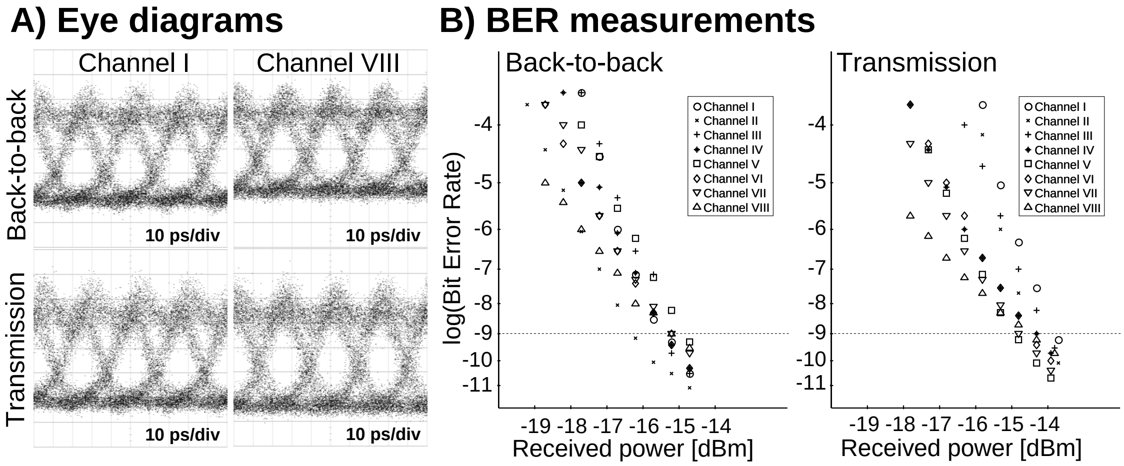

Fig. 3. The measured 40 Gbit/s eye diagrams and the result of the 8×40 Gbit/s BER measurements

Conclusions

In this paper we successfully present for the first time the low complexity and high capacity DWDM 8×40 Gbit/s over 38 km of SSMF transmission systems in the 1310 nm transmission window utilizing exclusively semiconductor components without any form of dispersion compensation. Taking into account the simplified system architecture the system will be characterized by the limited capital (integrable semiconductor components, lack of sophisticated electronics) and operational cost (low energy consumption and maintenance cost). The proposed transmission system can be utilized in parallel to the existing 1550 nm wavelength traffic therefore postponing or even omitting the expensive migration towards the advanced modulation formats based transmission or installation of new fibres. The proposed solution can be perfectly utilized in the data and storage center transmission systems as well as short and medium range metropolitan/campus networks. The presented system can perfectly support the short and medium range future 400G and 1T Ethernet transmission. Therefore we believe that the 1310 nm transmission window can be utilized to the advantages of the system and network operators, significantly expanding the current utilization.

Acknowledgements

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