Performance Analysis of 200-Gb/s Low Complexity Transmission in Second Window

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ABSTRACT

In this paper, a low complexity up to 200-Gb/s is analyzed over a 38-km standard single mode fiber transmission system in the 1310-nm wavelength domain. The system is based exclusively on semiconductor component without any form of dispersion compensation. The results showed that the 1310-nm wavelength domain can support low cost and low complexity high speed transmission.

Keywords

Optical fiber communication, electro absorption modulator, semiconductor optical amplifier, wavelength division multiplexing.

1. INTRODUCTION

An optical communication systems operating at multi-Gbit/s, such as 10 Gigabit Ethernet are becoming increasingly important in local area networks (LANs) and metropolitan area networks (MANs). The second generation 1310 nm wavelength domain is to realize high capacity, low cost and low complexity transmission. Demonstrated 1310 nm semiconductor based wavelength division multiplexing (WDM) systems operated at the distance below 100 km, therefore not fully exploiting advantages of the transmission in the 1310 nm transmission window. An error-free 8×20 Gbit/s 1310 nm dense WDM (DWDM) transmission using SOAs over 38 km of standard single mode fibre without any dispersion compensation. The whole system has simplified, cost-effective design. The current application of 1310 nm wavelength domain are limited to the upstream channel in fiber to the home systems as well as a newly developed 100G Ethernet standard,[6] where 4×25Gb/s transmission is utilized. Here we present semiconductor based 8×20 Gb/s and 8×25 Gb/s DWDM transmission over 38 km of SSMF in the 1310 nm wavelength domain[11]. Excellent operation of the system is demonstrated. A high speed and cost effectiveness transmission is achieved in the 1310 nm wavelength. The SSMF distance is proportional to the dispersion value and also to the square of the bit rate [3]. Therefore operation in the 1310 nm has an advantage of 10 times distance extension for a given bitrate without any dispersion component.

2. WORKING PRINCIPLE

Considering the SSMF fiber, transmission capacity of the 1310 nm wavelength domain will be limited by the residual chromatic dispersion as well as the four wave mixing effect (FWM).The transmitter consisted of eight continuous wavelength (CW) lasers at wavelengths: 1311.5-1321.2 nm (I-VIII), with the uniform channel spacing equal to 1.4 nm (250 GHz).The channel spacing between DWDM channels is limited by the FWM effect. Uniform adjacent channel spacing was applied. Below the 200GHz channel spacing the signal is significantly distorted by FWM, for the channel spacing >250 GHz the distortions are limited, while not significantly limiting the signal input power.

After passing through the polarization controllers all CW signals were combined in a following multiplexer. The 250 GHz channel spacing guaranteed sufficient suppression of the FWM effect. After multiplexer the signals entered an electro-absorption modulator (EAM). In the EAM all signals were modulated simultaneously at the bit rate 25-Gb/s with a pseudo random bit sequence coming from the pattern generator. To decorrelate the different wavelength channels a 2.5 km long dispersion shifted fiber (DSF) was used. Semiconductor optical amplifier (SOA) was used to compensate for the losses in the EAM, the DSF and to maximize the transmitter output power. The transmission line was based on the SSMF. After the transmission link, the signals entered a receiver which consisted of an SOA, a de-multiplexer and an electro- optical converter.

In the analysis, the 1-dB power penalty dispersion tolerance was set to 60 ps/nm and 38 ps/nm for the signals 20 Gb/s and 25 Gb/s, based on the conducted theoretical analysis and simulations. According to the Recommendation G.652 dispersion value limits in the 1310 nm transmission window. Dispersion values in the 1550 nm are usually ≈17 ps/nm×km. In the wavelength range 1306-1319 nm, dispersion value is at least 10 times lower than in the 1550 nm transmission window. Allowable transmission distance is inversely proportional to dispersion value and inversely proportional to the square of bit rate. At 10-Gbit/s transmission distance is limited to 60 km, at 25 Gbit/s to 10 km and at 40 Gbit/s to 3 km in the 1550 nm transmission window. Therefore operation in the 1306-1319 nm band has an advantage of 10 times distance extension for a given bit rate with respect to the 1550 nm transmission window without any dispersion compensation. The SSMF has attenuation of 0.3-0.4 dB/km around 1310 nm and 0.2- dB/km around 1550 nm..

3. SIMULATION SETUP

Fig. 1 shows the experimental setup of the low complexity DWDM transmission system in the 1310-nm transmission window. No dispersion compensation was applied. The utilized components were acquired from the commercial suppliers. All CW signals were combined in a multiplexer. After the multiplexer the signals entered an electro-absorption modulator (EAM). The EAM had the 3dB RF bandwidth of 39 GHz. In the EAM all signals were modulated simultaneously at the bit rate 20 Gigabits/s with the pseudo random bit sequence coming from the pattern generator.

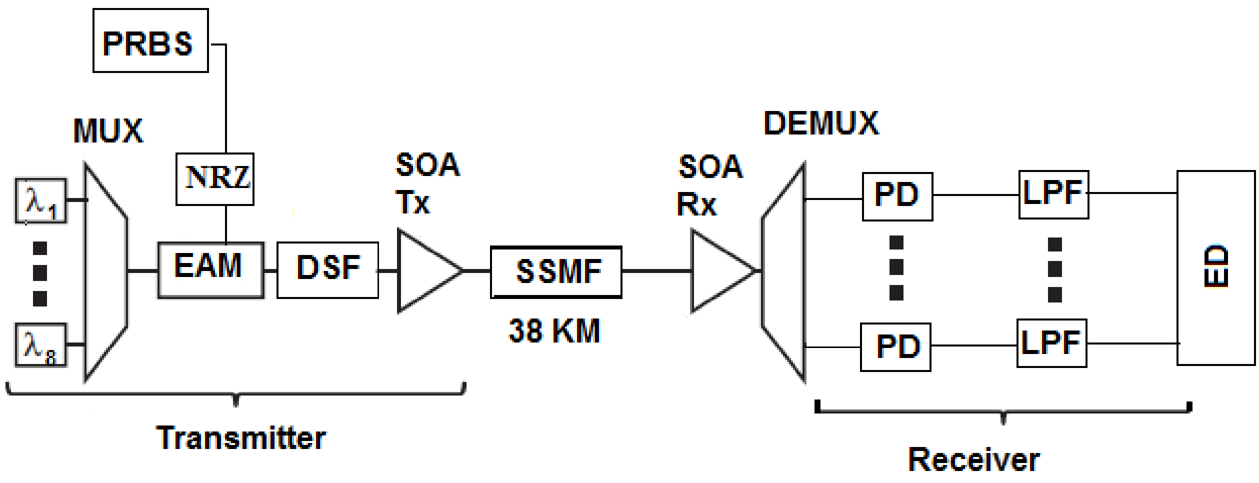

Fig 1: Experimental setup of the low complexity transmission system in the 1310-nm transmission window

To decorrelate the different wavelength channels dispersion shifted fiber (DSF) was used. The DSF had an absolute dispersion value of 42.5- ps/nm and an attenuation of 2 dB. To compensate the losses and to maximize the transmitter output power a semiconductor optical amplifier (SOA) booster was used. The booster SOA had a gain of 10.6 dB and a nominal saturation power of 13.0 dBm. After being simultaneously amplified in the SOA, all signals were injected into the transmission line.

Table 1. Parameters of standard single mode fiber

ATTRIBUTE	DETAIL	VALUE
Dispersion Coefficient	S_{0max}	0.092ps/nm^2×Km
Attenuation Coefficient	Maximum at 1310 nm	0.33-0.35 dB/Km
PMD Coefficient	Maximum PMD_Q	0.20 ps/√Km
Slope	At Reference wavelength	≤0.90 ps/(nm^2×Km)
Mode Field Diameter	At 1310nm	9.0±0.4μm

The transmission line was based on the SSMF [7] whose properties are listed in Table 1. The parameters of the transmission link were: the length 38.1 km, attenuation at 1310 nm 0.325 dB/km, the zero dispersion wavelength at 1316.3 nm, dispersion at 1310 nm 0.281 ps/nm*km and dispersion slope 0.087 ps/nm2*km. After the transmission link, the signals entered a DWDM receiver. The settings of the electrical signal remained unchanged during all measurements.

Table 2. Simulation Parameters

Bit rate	25 Gbps
Sequence length	128
Samples/bit	64
Channel spacing	1.4nm
Capacity	8-Channels 25-Gbps(200-Gbps)
Distance	10 Km, 40 Km
Input power	13 dBm, 20 dBm
Effective core area	65μm^2

The measured extinction ratio of the modulated 40 Gb/s signals was 8.5 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 simulation parameter is listed in Table 2. The DWDM receiver consisted of an SOA, a second AWG and an electro-optical converter. The preamplifying SOA had a gain of 15.7 dB and a nominal saturation power of 13.0 dBm. Next, all signals were fed into a demultiplexing.

4. SIMULATION RESULT

Fig. 2 shows the optical spectra after the transmission line. The spectrum resolution of 0.1 nm was chosen to verify presence of the FWM products. 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 on the sides of the data channels. The channel power levels are no longer equal after transmission due to the residual polarization and wavelength dependency of the utilized components, as can be observed in the spectrum.

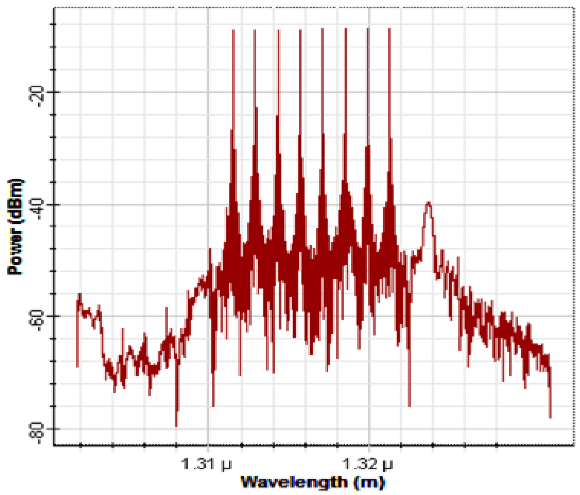

Fig 2: Optical spectra after the transmission line

When comparing the signal power levels in the experiments and simulations, note that the simulated signals were ideally copolarized, which increases efficiency of the FWM effect.

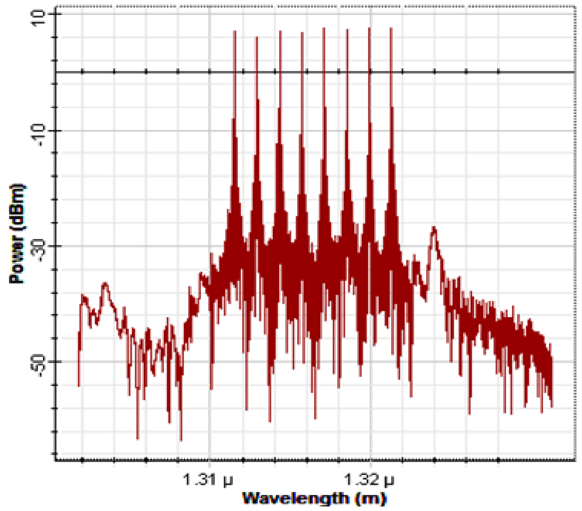

Fig 3: Optical spectra after the preamplifying SOA

Fig. 3 shows the optical spectra after the preamplifying SOA. After the preamplifying SOA the signal reaches a level of 2.2 dBm. The optical signal-to-noise ratio (OSNR) referenced to a 0.1 nm noise bandwidth dropped from 34.3 dB after the booster SOA to 31.3 dB after the pre amplifying SOA. The channel power levels are no longer equal after transmission due to the residual polarization and wavelength dependency of the utilized components, as can be observed in when comparing the signal power levels in the experiments and simulations, note that the simulated signals were ideally copolarized, which increases efficiency of the FWM effect.

Fig. 4 shows the measured eye diagrams for the channel I after the transmitter and before the photodiode. All other channels show a similar performance. 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 the residual saturation effects are visible in the transmitted signal shows the bit error rate (BER) measurement results. No error floor was observed. The spreading in the system performance is mainly caused by the wavelength and polarization dependence of the utilized components like the multiplexers and the SOAs as well as the fixed conditioning of the EAM driving electrical signal. After changing the PG bit rate to 20 Gb/s, without any changes in the system setup except the clock signal bypass, an overall system transmission capacity of 160 Gb/s was achieved..

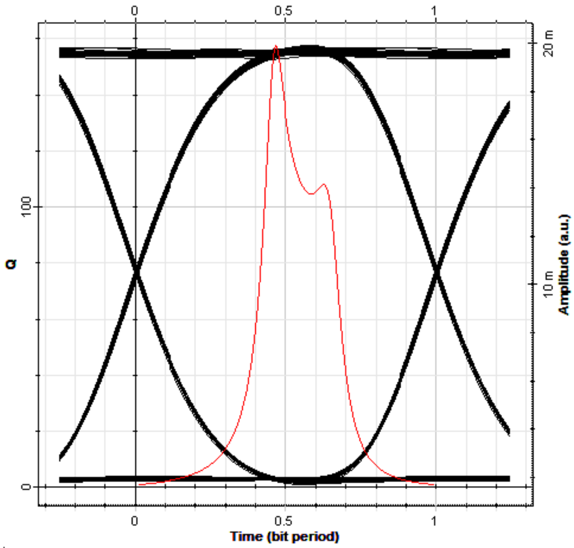

Fig 4: Measured 20-Gb/s eye diagram

Table 3 Simulation Results

CHANNELS	BIT RATE (Gbps)	LENGTH (Km)	Q Factor
8 Channels	25	10 Km	168.971
		20 Km	137.458
		30 Km	127.894
		40 Km	124.648
	20	10 Km	219.971
		20 Km	176.197
		30 Km	163.937
		40 Km	157.578

Fig.5 shows the measured 25-Gb/s Eye diagram for the channel I after the transmitter and before the photodiode. All other channels show a similar performance. 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 the residual saturation effects are visible in the transmitted signal. Figure 5 shows the bit error rate (BER) measurement results. The spreading in the system performance is mainly caused by the wavelength and polarization dependence of the utilized components like the multiplexers and the SOAs as well as the fixed conditioning of the EAM driving electrical signal.

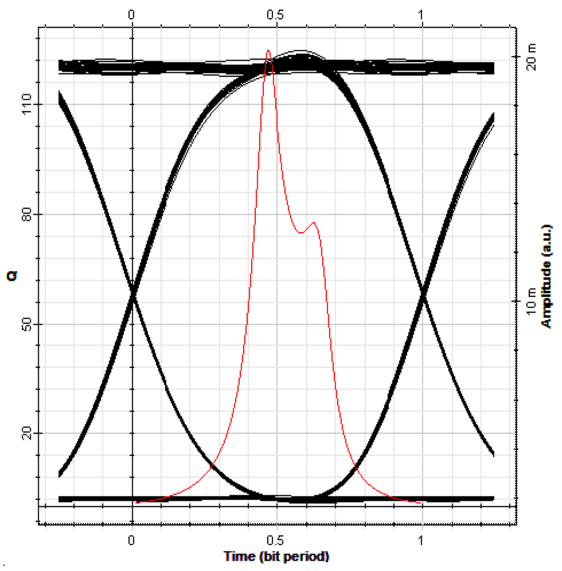

Fig 5: Measured 25-Gb/s eye diagram

After changing the PG bit rate to 25 Gigabit/s, without any changes in the system setup except the clock signal bypass, an overall system transmission capacity of 200-Gb/s was achieved

5. CONCLUSION

The low-complexity transmission system with the capacity up to 160 Gb/s in the 1310 nm wavelength domain, which allowed transmission of 8×20 Gb/s over 40 km of SSMF with the penalty of 0.8 dB and the average receiver sensitivity of −15 dBm. After increasing the line rate to 25-Gb/s overall transmission capacity of 200-Gb/s was achieved with the BER ≤2e−5. The presented system has simplified architecture and exclusively semiconductor components are utilized giving prospect for the photonic circuit integration. However, the SOA has in comparison with other optical amplification technologies, not optimal transmission properties, i.e. noise and saturation effects. For low input power signals the SOA output signal is affected by the amplified spontaneous emission (ASE) noise and for high input power signals by pattern effects. The influence of noise and saturation effects was verified in the simple experiment were four 10 Gbit/s NRZ channels were injected into the SOA and quality of one channel was evaluated in terms of bit error rate (BER) measurements. No dispersion compensation in the optical and electrical domain was applied. The 1310 nm wavelength domain can be utilized in parallel to the 1550 nm wavelength domain improving utilization of the legacy fiber infrastructure as well as exclusively, exploring its low-complexity and price advantage. The proposed system can perfectly support the short and medium range future 400G+ Ethernet transmission. Therefore we strongly believe that the 1310 nm wavelength domain can be utilized significantly expanding its current limited applications

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