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## THE INFLUENCE OF BINARY MODULATIONS IN OTDM

In this paper we propose a simulation test using different binary modulation formats in optical network based on the Optical Time Division Multiplexing (OTDM). OTDM in optical networks is used for high speed data generation in point-to-point networks. Dispersion and nonlinearities in optical fibers can cause transmission disturbances, which can influence the throughput of the transmission system and maximal achievable distance. Basic modulation formats RZ and NRZ with new CRZ and CSRZ formats were tested in OTDM simulation model.

**Keywords:** OTDM, modulation, RZ, NRZ, CSRZ, CRZ, BER, Q-factor.

### 1. Introduction

In addition to increasing user demands and new internet services like Triple Play, the requirement for greater bandwidth grows around 50–70% per year [1]. Copper wirings are close to their limits – both achievable distance and bandwidth. Optical fiber seems to be the best appropriate solution. Gradually, optical fibers spread from core networks to access networks.

Data transport in optical networks can be presented by the Time Division Multiplexing (TDM) and the Wavelength Division Multiplexing (WDM), where TDM can be realized electrically (ETDM) or optically (OTDM). OTDM has no electronics limitations and so can be used for high-speed data generation (actually the research groups achieved over 10.2 Tbps per one channel). In the comparison with limitation of ETDM networks, OTDM appears to be a solution for networks of next generations.

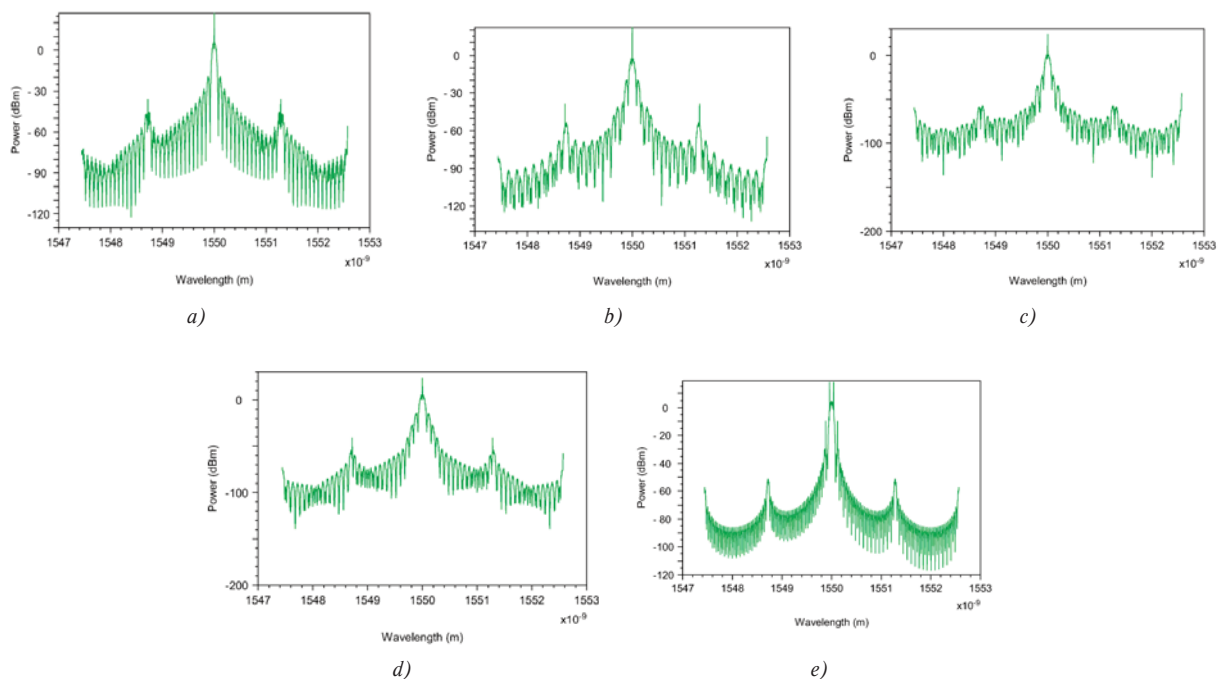


Fig. 1 Frequency spectrum of transmitted 160 Gbps OTDM signals at the output of multiplexer for modulation formats: a) NRZ, b) RZ 33%, c) RZ 50%, d) CRZ, e) CSRZ

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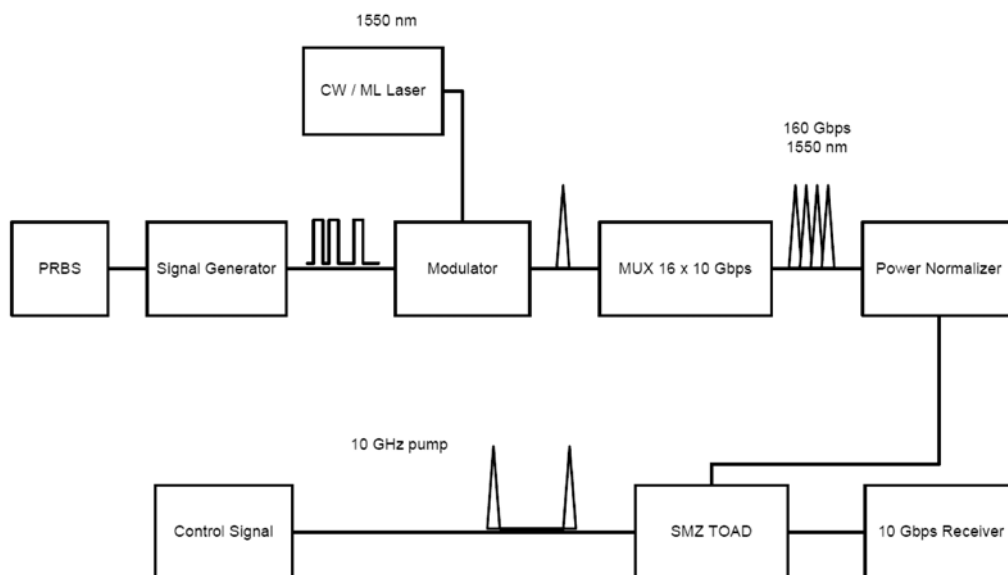


Fig. 2 Block scheme of the 160 Gbps OTDM network. Except the block modulator, the scheme was the same for all modulation formats

Throughput of every transmission system can be affected by nonlinearities and dispersions. Modulation formats have a big importance for transmission systems and could have a positive influence on maximal achievable distance and bit-rate. Except basic modulation formats the Non-Return-to-Zero (NRZ) and the Return-to-Zero (RZ), new types of modulation formats for optical networks were tested – the Chirped Return-to-Zero (CRZ) and the Carrier-Suppressed Return-to-Zero (CSRZ).

A) NRZ

NRZ is a main modulation format for transmission of data signal over optical fiber. Level of logical 1 takes the whole bit interval and in this duration the level of logical signal does not return to zero. The return to zero is caused by the change of the signal. Phase is 0 for the level of logical zero and  $\pi$  for the level of logical 1. In the comparison with other modulation formats, NRZ has a narrower spectrum of the central lobe and signal peaks are at multiples of the bit-rate [2].

B) RZ

The RZ modulation is based on return of the signal to logic zero. Pulses wide are shorter than bit interval wide. RZ is based on the NRZ modulation which is further modulated by a sinusoidal function. Commonly used formats are: RZ with 50% duty cycle, RZ with 33% duty cycle, RZ with 67% duty cycle (CSRZ). Pulses for all RZ signals have the same shape independent of the neighboring bit value. In the ideal modulation the pulse phases are identical. The central lobe of the optical spectrum of these RZ signals is wider than central lobe of the NRZ signal due to the narrower width of the RZ pulses [3].

C) CRZ

In CRZ a chirp is added to RZ by applying a phase modulation where the sinusoidal control voltage has twice the frequency

compared 50% RZ and oscillates twice the amplitude. Compared to classical RZ pulses phase is changed by  $\pi$  every following bit period. Carrier frequency is destructively affected and no peak is apparent on it, which improves the signal modulation [3].

D) CSRZ

In case of the CSRZ modulation the RZ optical signal after Mach-Zehnder modulator goes through a phase modulator driven by an analog sine wave generator at a frequency equal to half of the bit rate. That will introduce a  $\pi$  phase shift between any two adjacent bits and the spectrum will be modified so that the central peak at the carrier frequency is suppressed [4].

2. OTDM Simulation model

In OTDM narrow optical pulse lasers are used, hence it is possible to use extremely narrow time slots with a correspondingly high bandwidth. The higher bit-rate than for ETDM in one wavelength channel is achieved by multiplexing lower bitrates in an optical domain [5].

This section demonstrates simulation of 160 Gbps transmission and demultiplexing in OTDM network for different modulation formats. Simulations were done with OptSim software from RSoft Design Group [6]. The block scheme of simulation model in Fig. 2 is divided into 4 main parts – transmitter, control signal, the Symmetrical Mach-Zehnder Interferometer (SMZ) and receiver.

The transmitter part is based on  $16 \times 10$  Gbps data generation in sixteen channels on the same wavelength 1550 nm and with pseudorandom bit sequence. In this paper two almost same simulation models with same parameters were tested. Just the CW laser was used in the first model and the ML laser was used in the

second model (the default setups were used for both laser models). Pseudorandom bit sequence is modulated and then split in 8 directions. Every direction is delayed by 1/8 time window and multiplexed. The signal is multiplexed again by 1/2 time window. Spectra of the transmitted signals are shown in Fig. 1.

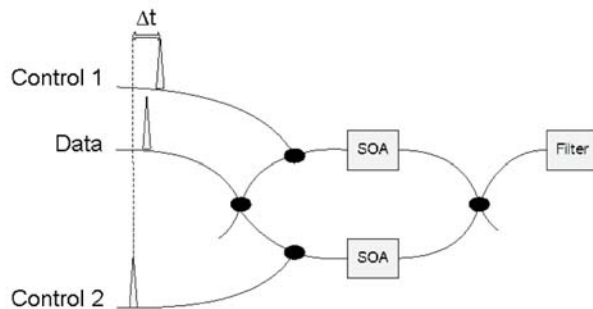


Fig. 3 TOAD based on Symmetrical Mach-Zehnder Interferometer

The important part of the Symmetrical Mach-Zehnder Interferometer (SMZ in Fig. 2) is 10 GHz control signal. The control signal is used for switching when it saturates the Semiconductor optical amplifier (SOA) in the loop and changes the index of refraction. Between two counterpropagating data pulses the differential phase shift is achieved for data pulses switching to the output port. SOA offset from the center position then provides switching window duration. The principle of the Terahertz Optical Asymmetric Demultiplexer (TOAD) based on SMZ is shown in Fig. 3.

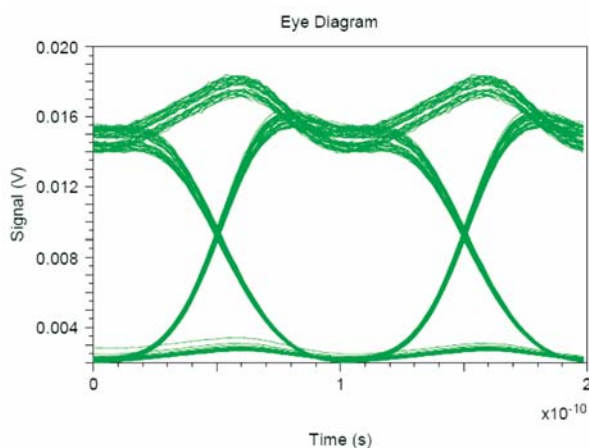


Fig. 4 Eye diagram for RZ 33% modulation with BER  $10^{-10}$

The output signal at the switching port carries data information of demultiplexed channel and suppressed interference from other channels. Fig. 4 shows corresponding Eye diagram of the switching port at the receiver part for the RZ modulation.

### 3. Description of the parameters

The main parameters for assessing the quality are the Bit Error Rate (BER) which shows the signal to noise ratio, Eye diagram and Q-factor.

The Q-factor is a performance estimator. It shows the quality of the signal with regard to the signal to noise ratio (SNR). This includes all physical signal disturbances. These disturbances reduce the quality of the signal and cause bit errors [4]. Consequently, the higher Q-factor ratio means a better signal to noise ratio and thus lower BER. The BER is approximately [4]:

$$BER \approx 0.5 \operatorname{erfc}\left(\frac{Q}{\sqrt{2}}\right) \quad (1)$$

The BER expresses the frequency of bit errors given by the ratio of the incorrectly transmitted elements in a digital signal to the total number of transferred elements [4].

In telecommunication systems an eye pattern (Eye diagram) is an oscilloscope display where the vertical input repetitively sampled a digital data signal from the receiver and data rate is used to trigger the horizontal sweep. From the Eye diagram is possible to offer some other parameters like jitter, Eye Amplitude, Eye Delay or Intersymbol Interference (ISI), which shows the interleaving of the modulation pulses.

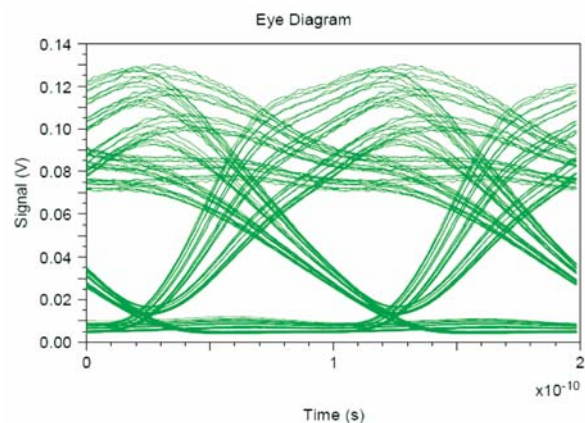


Fig. 5 Eye diagram for NRZ modulation with BER  $10^{-2}$

Corresponding Eye diagrams with good BER and with low BER are shown in Fig. 4 or in Fig. 5.

### 4. Results

The spectra of transmitted signals are shown in Fig. 1. The central peaks of all transmitted signals are set to 1550 nm wavelength. Both NRZ and CSRZ have a similar narrow power spectrum peak, but the CSRZ modulation does not have a chirp in the middle of the carrier frequency. Absence of this chirp in the central

of the carrier frequency reduces the intersymbol interference. The CRZ modulation has a wider spectrum than other modulation formats and is less affected by nonlinearities (but a wider spectrum is worse for WDM systems).

Results of BER and Q-factor for all modulation formats for both lasers Table 1

CW Laser			ML Laser		
Modulation	BER [-]	Q <sub>dB</sub> [dB]	Modulation	BER [-]	Q <sub>dB</sub> [dB]
NRZ	2.16E-02	6.11E+00	NRZ	9.77E-15	1.77E+01
RZ 33 %	1.16E-10	1.60E+01	RZ 33 %	5.40E-13	1.71E+01
RZ 50 %	2.35E-13	1.72E+01	RZ 50 %	3.56E-15	1.78E+01
CRZ	1.14E-13	1.73E+01	CRZ	3.26E-17	1.84E+01
CSRZ	5.53E-18	1.87E+01	CSRZ	1.33E-05	1.25E+01

Note that the widely accepted definition is used to express the factor in decibel units.

As shown in Fig. 6 the best BER was achieved with the CSRZ modulation and CW laser in transmitter. The worst BER (2.16 E-2) was achieved with the CW laser and NRZ modulation. This value is low and the system could not correctly recognize the signal. Results of the Q-factor and BER for all modulation formats are shown in Table 1.

Graphs of the Q-factor and BER (Figs. 6 and 7) show all modulation formats with their values. As you can see with a higher Q-factor also BER grows. The minimal value of BER for the correctly recognized signal should be about  $10^{-5}$  and for the Q-factor about 4 dB.

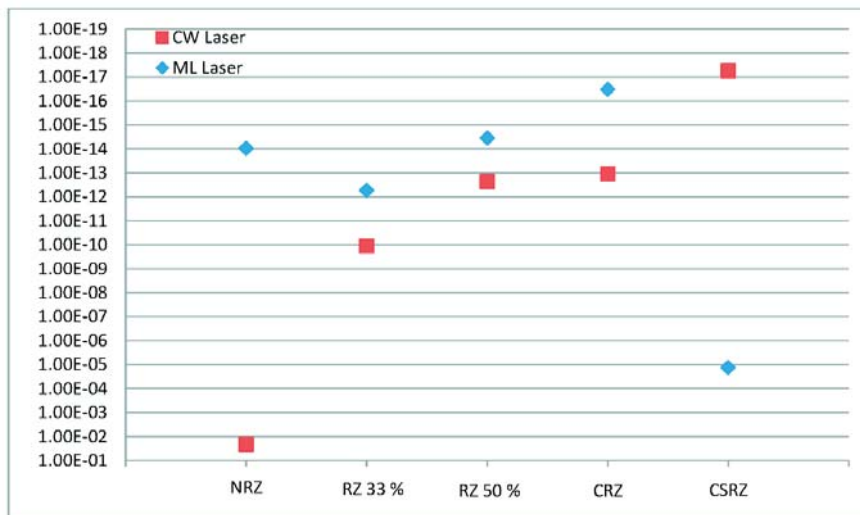


Fig. 6 Graph of comparison BER parameter for all modulation formats for both lasers

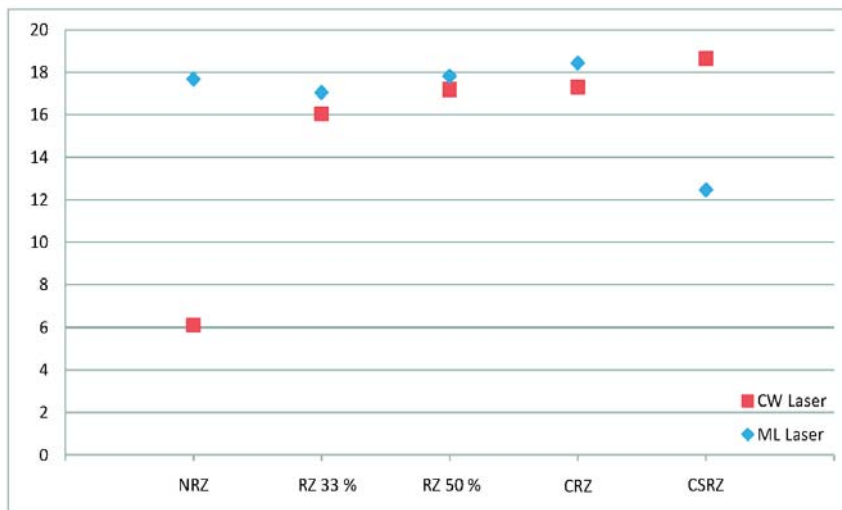


Fig. 7 Graph of comparison Q-factor parameter for all modulation formats for both lasers

## 5. Conclusion

In this paper new modulation formats for OTDM were tested. At present the NRZ modulation format is the most used format for optical communications because of its simple implementation and good transmit parameters. From the results you can see that other modulation formats (RZ, CSRZ and CRZ) had better parameters in the tested OTDM models and could be used in optical communications. The CSRZ modulation due to its good tested transmit parameters should be used for longer distances. The CRZ

modulation then should be used in optical networks with big influence of nonlinearities and dispersions. Laser also has big influence on the transmitted signal. With mode lock lasers the short pulses can be generated and, therefore, these lasers are more suitable for high-speed data generation.

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