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Investigation of Mixed Data Rate and Format Transmission in WDM Networks.

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Introduction

For a long time, non-return-to-zero (NRZ) has been the dominant modulation format in intensity modulation direct detection (IMDD) fibre optical communication systems. The major reasons for using NRZ in the early days of fibre optical communication were a relatively low electrical bandwidth for the transmitters and receivers compared to return-to-zero (RZ) [1]. In general, NRZ modulated optical signal has the most compact spectrum compared to that with other modulation formats. However, this does not mean that NRZ optical signal has superior resistance to residual chromatic dispersion in an amplified fibre system. In addition, NRZ modulated optical signal has been found to be less resistive to fibre nonlinearities [4].

RZ modulation has become a popular solution for 10 Gbit/s systems because it has a higher peak power, a higher signal-to-noise ratio (SNR), and lower bit error rate (BER) that NRZ encoding. Despite these advantages, conventional RZ signal is not well suited for the use in dense wavelength division multiplexing (DWDM) systems due to its broad spectral width [4].

By encoding multiple bits per symbol, non-binary modulation techniques can accomplish significant spectral efficiency. Spectral narrowing alone can also reduce the effect of chromatic dispersion. Encoding multiple bits per symbol also gives rise to longer symbol duration that can in turn increase robustness to fibre propagation impairments. Duobinary (Duo) is a three level code which substantially reduces the bandwidth occupancy of a signal compared to coding with NRZ or RZ [5].

In recent years, as optical communication is advancing to mixed data rates, NRZ, RZ and Duobinary modulation formats must be investigated for the future mixed transmission in dense wavelength division multiplexing (DWDM) systems, where NRZ modulation format may not be the best choice for high capacity optical systems. However, due to its simplicity, and its historic dominance, NRZ can be used as a good foundation for the purpose of mixed data rate and format transmission.

Mixed WDM systems have several problems to be overcome. These problems include wavelength dispersion, dispersion slope, polarization-mode dispersion, and nonlinear effects of the transmission line. Other critical issues are the linear and nonlinear crosstalk from adjacent channels and the cost increase of the mixed WDM signal control. Therefore, the complete understanding of multiform signals mixed transmission is compulsory for futures WDM networks.

Measurement technique

Our research is based on the evaluation such system parameter as the bit error rate (BER) using powerful techniques which are incorporated in OptSim 4.7 simulation software. In the present work, we show spectrum and eye diagrams for various simulation setups, since they are a fast way how to approximately evaluate a system performance; respectively, an eye has to be opened wide enough and spectrum diagrams should be regulars without negative multipeak structure for good system performance. An eye diagram shows the patterns of the electrical signal after detection. The eye height is an indicator of noise, whereas the signal width at the centre of an eye diagram represents a measure of timing jitter. The use of simulation software allows for preliminary results, though precise enough to be considered as true [2].

The accepted method of calculation is based on the solving a complex set of differential equations, taking into account optical and electrical noise as well as linear and nonlinear effects. We used model where signals are propagating as time domain samples over a selectable bandwidth (in our case, a bandwidth that contains all channels). The Time Domain Split Step (TDSS) method was employed to simulate linear and nonlinear behaviour for both optical and electrical components. The Split Step method is used in all commercial simulation tools to perform the integration of the fibre propagation equation:

$$\frac{\partial A(t,z)}{\partial z} = \{L + N\} A(t,z). \qquad (1)$$

Here $A(t,z)$ is the optical field, L is the linear operator that stands for dispersion and other linear effects, and N is the operator that is responsible for all nonlinear effects. The idea is to calculate the equation over small spans of fibre Δz by including either a linear or a nonlinear operator. For instance, on the first span Δz only linear effects are considered, on the second – only nonlinear, on the third – again only linear ones, and so on. Two ways of calculation are possible: Frequency Domain Split Step (FDSS) and the above mentioned Time Domain Split Step (TDSS) methods. These methods differ in how linear operator L is calculated: FDSS does it in a frequency domain, whereas TDSS - in the time domain by calculating the convolution product in sampled time. The first method is easy to fulfil, but it may produce severe errors during computation. In our simulation we have employed the second method, TDSS, which, despite its complexity, ensures an effective and time - efficient solution [3].

Simulation scheme

A large number of publications in the world are devoted to modulation formats, starting from the elaboration of novel efficient numerical methods and ending with the creation of complex multiform WDM systems. The aim of our simulation was to compare the various modulation formats (NRZ/RZ/Dou) complex transmission at different bit rates (2.5/10 Gbit/s) and found the most resilient solution for mixed WDM network Fig.1. In particular, the optical power spectrum and the spectral bandwidth of the different signals are investigated at the multiplexer/demultiplexer output/input ports. These results together with dispersion and nonlinear effects will be compared to the system performance of optical network.

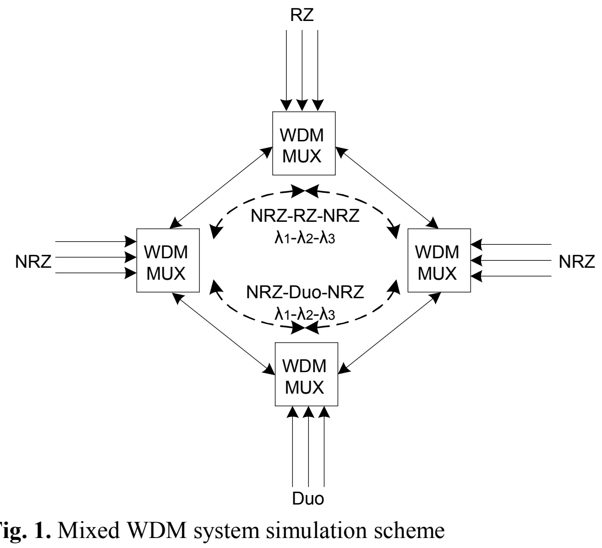

Fig. 1. Mixed WDM system simulation scheme

The transmitter block consists of 3 multiplexed channels, each of them consisting of a data source, a driver, a laser and external modulator [3]. The data source produces a bit stream that presents the information to be transmitted via fibre optical link. Then we need a driver, which forms different code pulses from incoming bits. The pulses are then modulated with continuous wave (CW) laser radiation to obtain optical pulses.

After the transmission block the signal is sent directly to a standard-single mode fibre (SSMF), where optical pulses are propagating over a different distances. The used fibre has a large core effective area 80 μm^2, other parameters being: attenuation α = 0.2 dB/km, dispersion D = 16 ps/nm·km, dispersion slope D_{sl} = 0.07 ps/nm^2·km, and nonlinear refractive coefficient n_k = 2.5·10^{-20} cm/W at the reference wavelength λ = 1550 nm. At the fibre end the channels are demultiplexed, so that each channel could be analyzed separately. After that, each channel is optically filtered, converted to electrical one and then electrically filtered. To evaluate the system performance several measurements have been taken. We were interesting in observing the optical spectrum at the beginning and at the end of optical link, as well as eye diagrams and BERs quantity.

The idea is to compare the different mixed WDM system performance when using distinctive modulation formats simultaneously.

Results and discussions

The aim of this section is to verify systems simulation with the integrated OptSim package and to numerically evaluate and compare the performance of mixed -NRZ-, -RZ- and-Duo- modulation formats in WDM systems with typical system parameters.

The eye pattern is a powerful, yet simple time-domain tool for assessing the data capability of an optical digital transmission system. The eye pattern measurements are made in the time domain and in real time showing the effects of waveform distortions immediately on an oscilloscope. Much system performance information can be deduced from the eye-pattern display. Information regarding the signal amplitude distortion, timing jitter and system rise time can be derived simply by observing certain features of the pattern. The eye-pattern obtained during simulations will be analyzed to obtain and to compare various system performance characteristics.

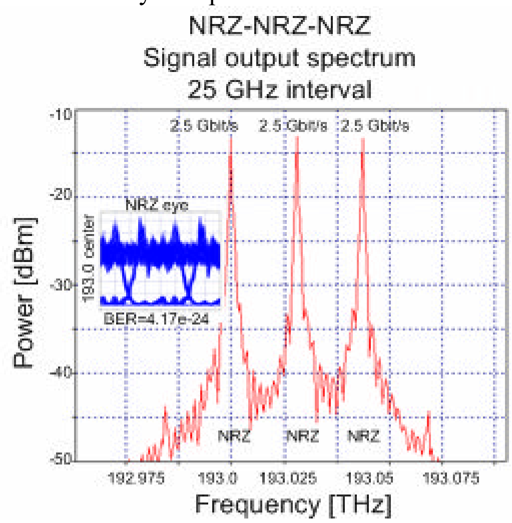

Fig. 2. NRZ-NRZ-NRZ output optical signal spectrum and output eye pattern of a 3-channel WDM system, after 80 km of SSMF

Fig. 2 depicts output optical signal spectrum and electrical signal eye pattern for NRZ format 2.5 Gbit/s WDM system where 25 GHz channel interval is presented.

That solution indicates that for 50 GHz ITU-T standard channel spacing can be two times reduced and the BER value still sufficient for good system performance. For 10 Gbit/s WDM system 25 GHz channel interval is not suitable mainly of signal distortion. Fig. 3 shows an optimal channel spacing for 10 Gbit/s NRZ format WDM system.

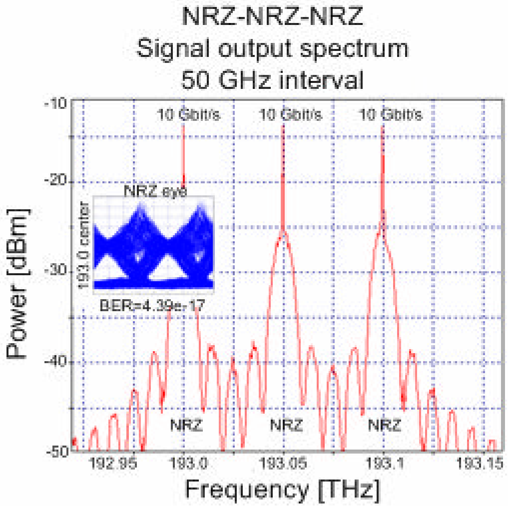

Fig. 3. NRZ-NRZ-NRZ output optical signal spectrum and output electrical eye pattern of a 3-channel WDM system, after 80 km of SSMF

For the next generation WDM systems the mixed signal formats transmission will be necessity. Figure 4 presents output optical signal spectrum and electrical signal eye patterns for NRZ-RZ-NRZ mixed formats.

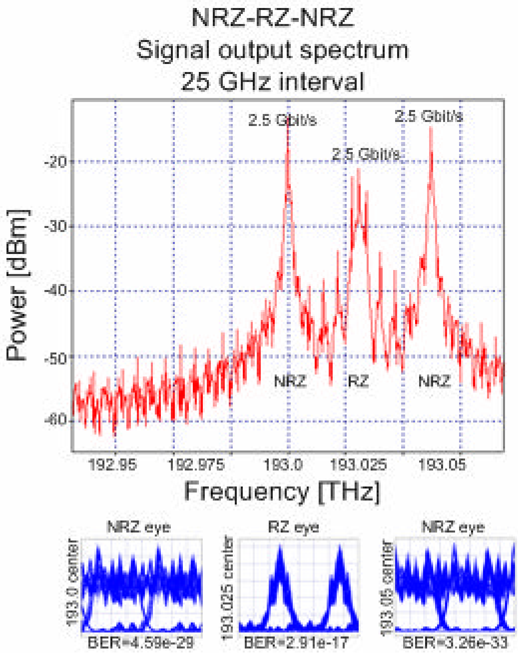

Fig. 4. NRZ-RZ-NRZ output optical signal spectrum and output electrical eye patterns of a 3-channel mixed WDM system, after 80 km of SSMF

This example shows that optimal channel spacing for mixed NRZ-RZ-NRZ 2.5 Gbit/s systems should be more than 25 GHz. For mixed data rates in the same system an optimal channel interval should be more than 50 GHz, and only in that case the maximum transmission distance stay unchanged Fig. 5.

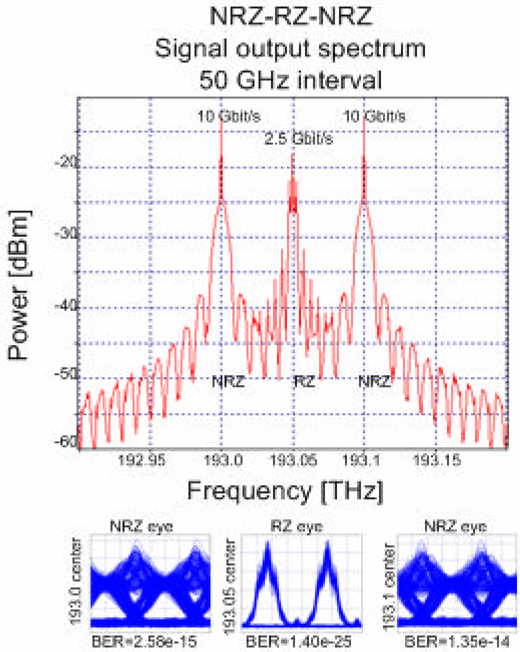

Fig. 5. NRZ-RZ-NRZ output optical signal spectrum and output electrical eye patterns of a 3-channel mixed WDM system, after 80 km of SSMF

Fig. 6 depicts output optical signal spectrum and electrical signal eye patterns for NRZ-Duo-NRZ mixed formats where the most perspective Duobinary modulation format is presented.

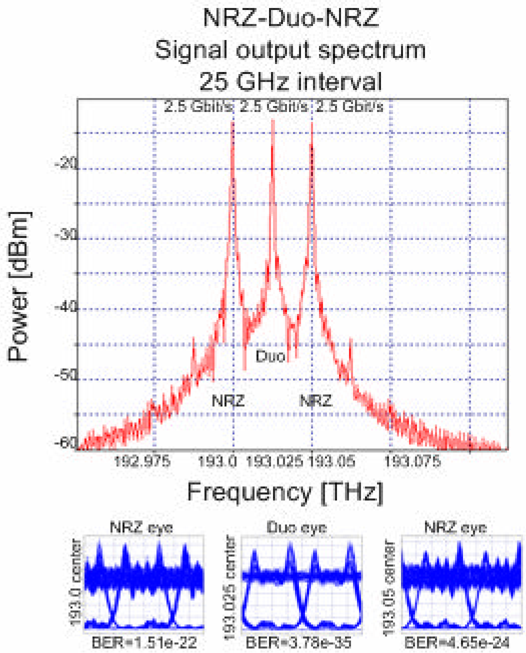

Fig. 6. NRZ-Duo-NRZ output optical signal spectrum and output electrical eye patterns of a 3-channel mixed WDM system, after 80 km of SSMF

Non-binary modulation technique can perform significant spectral efficiency. In our case NRZ-Duo-NRZ mixed transmission shows great signals quality on output and to increase the bit rate of each channel up to 10 Gbit/s system characteristics remains settled Fig. 7.

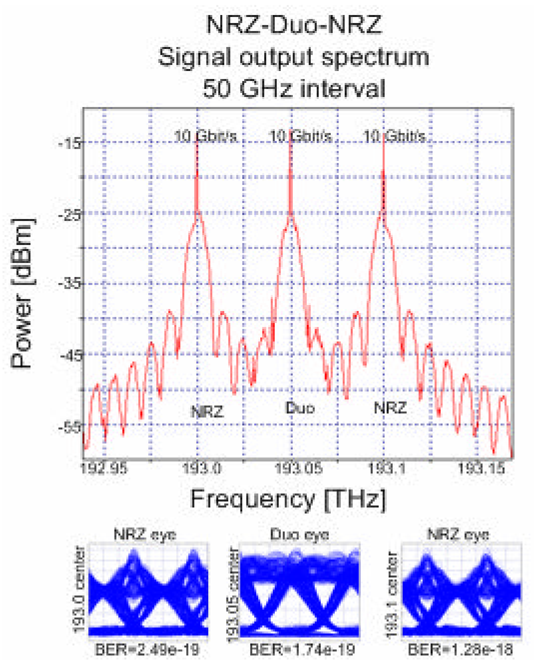

Fig. 7. NRZ-Duo-NRZ output optical signal spectrum and output electrical eye patterns of a 3-channel mixed WDM system, after 80 km of SSMF

Conclusions

In this report we have investigated the performance of mixed 2.5 Gbit/s and 10 Gbit/s optical systems with simultaneous propagation of various modulation formats. For mixed WDM systems with 25 GHz channel spacing, nonlinear crosstalk originated from cross phase modulation and four-wave mixing are the major source of system performance degradation.

Dispersion limited distances for conventional NRZ external modulated systems at 10 Gbit/s is about 80 km, for the mixed 10 Gbit/s NRZ-RZ-NRZ system these distances is two times shorter.

Traditional 10 Gbit/s NRZ and 10 Gbit/s mixed NRZ-Duo-NRZ WDM systems have similar transmission properties and equally efficient for 80 km, and efficient channel interval should be more than 50 GHz.

Compared together all investigated modulation formats, it can be seen that all of them can be used for future mixed traffic transmission in WDM networks.

Acknowledgement

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V. Bobrovs, G. Ivanovs. Investigation of Mixed Data Rate and Format Ttransmission in WDM Networks // Electronics and Electrical Engineering. – Kaunas: Technologija, 2008. – No. 4(84). – P. 63-66.

Simultaneous propagation of different modulation formats in WDM systems are evaluated numerically with OptSim simulation software at a bit rate of 2.5 Gbit/s and 10 Gbit/s using 80 km fibre length. The obtained results show the flexibility of mixed WDM networks and usability in futures solutions. Ill. 7, bibl. 5 (in English; summaries in English, Russian and Lithuanian).

В. Бобровс, Г. Ивановс. Исследование смешанной нормы данных и передачи формата в сетях WDM // Электроника и электротехника. – Каунас: Технология, 2008. – № 4(84). – С. 63–66.

Одновременное распространение различных форматов модуляции в системах WDM оценено в цифровой форме с программным обеспечением моделирования OptSim по небольшому количеству нормы 2.5 Gbit/s и 10 Gbit/s использование 80-километровой длины волокна. Полученные результаты проявляют гибкость смешанных сетей WDM и удобства и простоты использования в решениях для фьючерса. Ил. 7, библ. 5 (на английском языке; рефераты на английском, русском и литовском яз.).

V. Bobrovs, G. Ivanovs. Sumaišytų duomenų lygių ir formato perdavimo WDM tinkluose tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2008. – Nr. 4(84). – P. 63–66.

Ištirtas ir įvertintas vienalaikis skleidimas skirtingų moduliacijos formatų WDM sistemose skaičiumi su Optsim modeliavimo programine įranga pagal lygius 2,5 Gbit/s ir 10 Gbit/s naudojant 80 km ilgio optinį pluoštą. Gauti rezultatai rodo lankstumą sumaišytų WDM tinklų ir panaudojimo patogumą ateities sprendimuose. Il. 7, bibl. 5 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).