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Investigation of Different Modulation Formats Simultaneous Transmission in WDM Systems

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Introduction

Protractedly, intensity modulation (IM) format has been the dominant in wavelength division multiplexing (WDM) transmission systems. The major reasons for using were a relatively simple realization of optical transmitter and receiver compared with phase modulation (PSK) format [5].

In fiber optical transmission systems, the degradation effects can be categorized by the random noise and waveform distortion which are generated by chromatic dispersion, polarization mode dispersion, fiber nonlinearity, or their combination [9]. In WDM systems the Kerr nonlinearities, such as self-phase modulation (SPM), cross-phase modulation (XPM) and four-wave mixing (FWM) are the main signal degradation factors [5].

A mixed WDM system carries signals by its individual wavelength, and provides its flexibility in utilizing of different modulation formats. Mixed WDM systems with equal transmission technique is a natural choice to distribute both IM and PSK signals simultaneously. There are several mixed WDM systems explored previously with intensity modulation such as simultaneous transmission of different bit rates or code formats [2, 4].

In recent years, as fiber optical communication is advancing to mixed signals broadcasting IM and PSK formats simultaneous transmission must be investigated for future WDM solutions, since there are neither agreed recommendations nor standards for mixed WDM systems. However, due to IM simplicity, and its historic dominance, it can be used as a good foundation for the purpose of mixed signals transmission. To realize the simultaneous transmission of IM and PSK signals in WDM network, the system's design and optimization have to take into account all the contributing factors - such as the signal optical power, channel interval and fiber dispersion [6].

This work demonstrates a simultaneous IM and PSK formats utilization in WDM system and show potentialities of future mixed transmission.

Simulation technique

Our research is based on the evaluation such system parameters as the bit error rate (BER) and optical signal to noise ration (OSNR) using powerful techniques which are incorporated in OptSim 5.0 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 [3].

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; *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 [10].

Simulation model

A large number of publications in the world are devoted to WDM systems, starting from the elaboration of novel efficient numerical methods and ending with the creation of original WDM systems [6, 7]. The idea of our investigation was to evaluate the performance of mixed WDM system where simultaneously used intensity and phase modulation techniques.

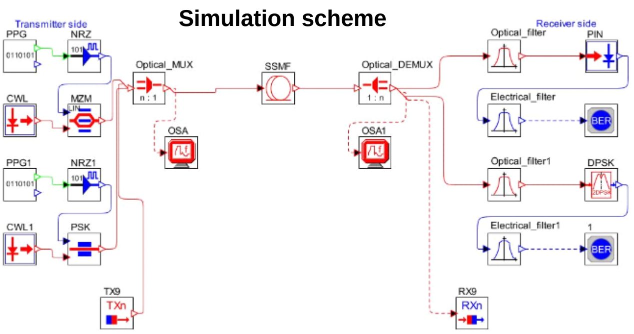

Fig. 1. Simulation model of mixed WDM system

Fig. 1 shows the simulation model of the mixed WDM system with a link length of 40 km (recommended link length for 10 Gbit/s solutions without dispersion compensation modules). The transmitter block consists of maximum nine externally modulated outputs, each of them consisting of a data source, a driver, a laser and external Mach-Zehnder (MZ) modulator [1]. The laser is always switched on and its light waves are modulated via the electro-optic MZ modulator by data pulse sequence output of a pulse pattern generator (PPG), using the principles of interferometric constructive and destructive interference to present ON and OFF of the light waves. Such way of modulation is called intensity modulation. To perform optical signal phase modulation it is possible to use the same MZ modulator, because of optical signal intensity and phase together modulation [5].

After the transmission block the signal is sent directly to a standard-single mode fibre (SSMF). 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 $n_k = 2.5 \cdot 10^{-20}$ 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 end of optical link, as well as eye diagrams and BERs quantity.

The idea is to change the main parameters (channel interval, optical power and dispersion level) of prepared mixed WDM system and evaluate the characteristics of transmitted signals.

Results and discussions

The aim of this section is to numerically evaluate the performance of mixed WDM system when using optical signal intensity and phase modulation formats simultaneously at different wavelengths.

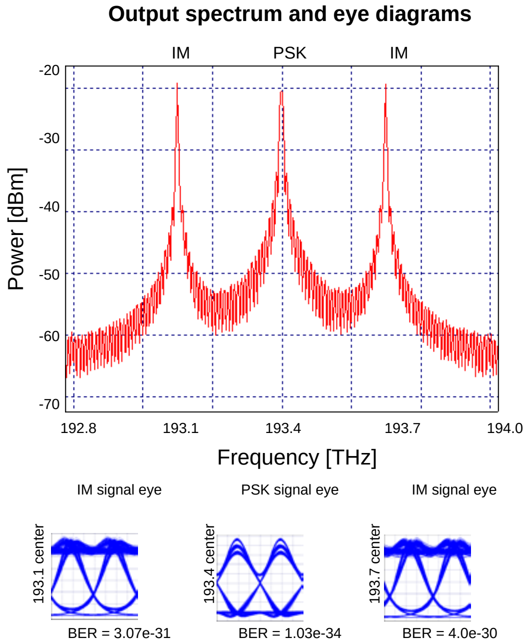

Fig. 2. Simplest mixed WDM system output spectrum after 40 km fiber length. Received eye diagrams for 10 Gbit/s data signals, 300 GHz channel interval

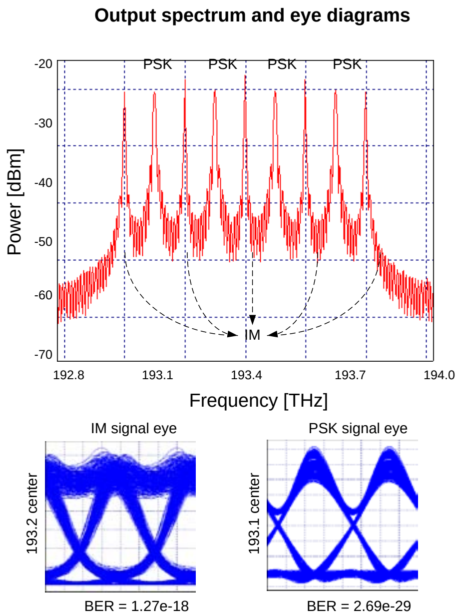

Fig. 3. Mixed WDM system output spectrum after 40 km fiber length. The worst received eye diagrams presented for each modulation technique, 100 GHz channel interval

The first simulation Fig. 2 was developed to preview the output results of simplest mixed WDM system, where three channels are used.

Fig. 2 depicts output optical signal spectrum and electrical eye diagrams for 10 Gbit/s WDM system where 300 GHz channel interval is presented. This example shows that it is possible to successfully transmit mixed WDM signals with IM and PSK techniques. Each signal quality (BER - bit error ratio) is less than 10^{-9}.

When reducing channel spacing for a given bit rate per channel to increase spectral efficiency in mixed WDM systems, interchannel interference (ICI) and nonlinear effects become more and more significant [8].

The second simulation Fig. 3 was developed to demonstrate the mixed WDM system performance where frequency interval was reduced to 100 GHz and channel number increased till nine.

Fig. 3 presents output optical signal spectrum and the worst eye diagrams on output for each modulation technique. As we can see, the BER value is still sufficient and further optimization is possible Fig. 4.

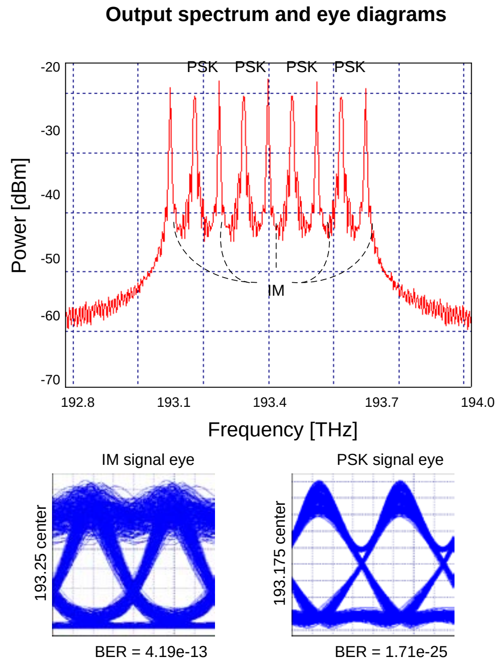

Fig. 4. Mixed WDM system output spectrum after 40 km fiber length. The worst received eye diagrams presented for each modulation technique, 75 GHz channel interval

Fig. 4 depicts output optical signal spectrum and the worst eye diagrams on output for each modulation technique, where the optimal channel interval was founded. The channels were shifted till effective eye diagram presented on oscilloscope and the optical signal-to-noise ratio (OSNR) was enough for good system performance. It can be seen, that 75 GHz frequency interval is the minimal allowed spacing till BER level exceeded.

Major reasons for signals degradation in fiber optical communication systems are the dispersion level of the fiber and nonlinearity due to high power loading at the input. For that reason, Fig. 5 demonstrates mixed WDM system protection from Kerr nonlinearities.

Fig. 5 presents the mixed WDM system performance where frequency interval was reduced to 100 GHz and lasers output power increased from 0 dBm till 10 dBm. In that case, mixed WDM system still efficient, the BER value of each channel not more than allowed level. From spectrum diagram is understandable that new generated harmonics power not enough for system performance degradation.

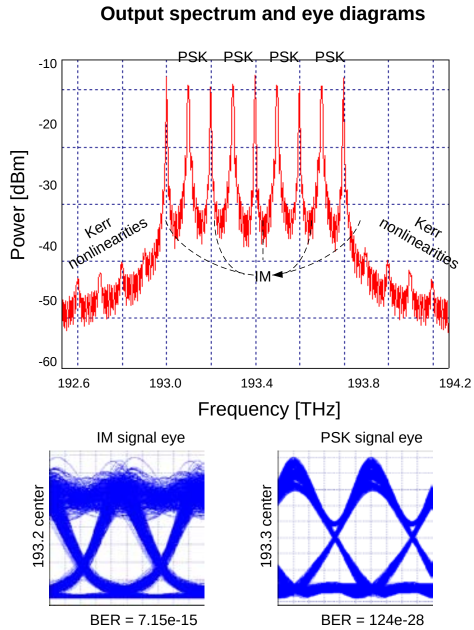

Fig. 5. Mixed WDM system output spectrum after 40 km fiber length. The worst received eye diagrams presented for each modulation technique, 100 GHz channel interval and 10 dBm output power

The fundamental limitation on the high speed of communications systems over the SSMF are the linear chromatic and polarization mode dispersions. It is possible to realize WDM transmission in zero dispersion regions to use optical fibers with shifted dispersion Fig. 6.

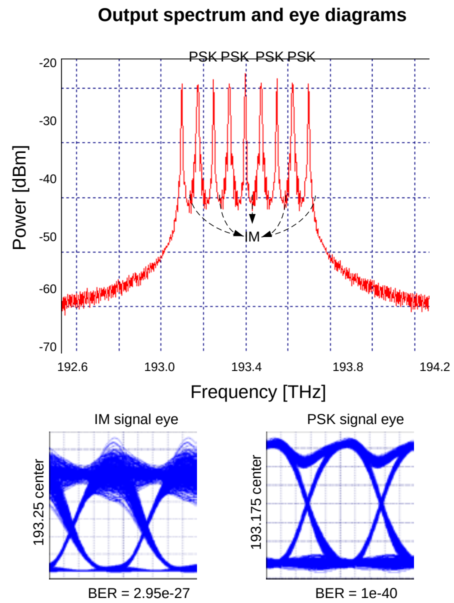

Fig. 6. Mixed WDM system output spectrum after 40 km fiber length. The worst received eye diagrams presented for each modulation technique, 75 GHz channel interval and DSF fiber is installed

Fig. 6 depicts output optical signal spectrum and the worst eye diagrams on output for each modulation technique, where channel interval was reduced till 75 GHz and SSMF changed to dispersion shifted fiber (DSF). That solution shows that decreased dispersion level of optical fiber improved the mixed WDM system signals characteristics.

Conclusions

In this report we have investigated the performance of mixed 10 Gbit/s optical systems with simultaneous propagation of intensity and phase modulation formats. For that type of mixed WDM systems, nonlinear crosstalk originated from Kerr nonlinearities are the major source of system performance degradation.

In contrast to the conventional WDM systems, we demonstrate the minimal allowed 75 GHz channel spacing in mixed transmission. It can be seen that IM and PSK formats can be certainly used in simultaneous transmission. After laser output optical power increasing from 0 dBm to 10 dBm the system characteristics remains stable and BER quality under allowed level. Our calculation have shown that, the dispersion level reducing in the system improve network performances.

Our recommendations for mixed WDM transmission are only the first step for successful broadcasting and the future optimization will be necessary.

Acknowledgements

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V. Bobrovs, G. Ivanovs. Investigation of Different Modulation Formats Simultaneous Transmission in WDM Systems // Electronics and Electrical Engineering. – Kaunas: Technologija, 2010. – No. 7(103). – P. 109–112.

For a long time, intensity modulation (IM) format has been the dominant in wavelength division multiplexing (WDM) transmission systems. The major reasons for using were a relatively simple realization of optical transmitter and receiver compared with phase modulation (PSK) format. However, IM format has been less resistive to fiber nonlinearities. In recent years, as fiber optical communication is advancing to mixed signals broadcasting IM and PSK formats simultaneous transmission must be investigated**.** Ill. 6, bibl. 10 (in English; abstracts in English, Russian and Lithuanian).

В. Бобровс, Г. Ивановс. Исследование одновременной передачи различных форматов модуляции в WDM системах // Электроника и электротехника. – Каунас: Технология, 2010. – № 7(103). – С. 109–112.

Продолжительное время, формат модуляции интенсивности (МИ) сигнала был доминирующим в WDM системах передачи. Основной причиной использования служила простая реализация оптических передатчиков и приёмников по сравнению с форматом фазовой модуляции (ФМ) сигнала. Однако МИ формат менее устойчив к волоконным нелинейностям. В последние годы наметилась терденция использования комбинированной передачи сигналов, поэтому необходимо исследовать одновременную передачу ИМ и ФМ форматов. Ил. 6, библ. 10 (на английском языке; рефераты на английском, русском и литовском яз.).

V. Bobrovs, G. Ivanovs. WDM sistemos tyrimas, naudojant skirtingus signalų perdavimo moduliacijos variantus // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 7(103). – P. 109–112.

Aprašomos galimybės naudoti optinius siųstuvus ir imtuvus, kai signalai moduliuojami faze. Daugiausia dėmesio skiriama fazinės moduliacijos formatui ir signalų perdavimo įvairovei įvertinant šiandieninę mokslų plėtros tendenciją. Eksperimentiškai patikrinta IM ir PSK formatų įtaką WDM sistemose. Il. 6, bibl. 10 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).