

## Investigation of Minimal Channel Spacing in HDWDM Systems

**V. Bobrovs, G. Ivanovs**

*Department of Telecommunications, Riga Technical University*

*Azenes st. 12, LV-1010 Riga, Latvia, phone: +371 29566682, e-mail: vjaceslavs.Bobrovs@rtu.lv*

### Introduction

Owing to the rapidly growing capacity requirements for long distance transmission, fiber optic telecommunications are advancing into high data rate and dense channel schemes enabled by wavelength division multiplexing (WDM). In order to maximize the system capacity and to minimize the performance degradation caused by transmission impairments the system investigation and optimization are very important [1].

In fiber optical transmission systems, the degradation effects can be categorized by the random noise and waveform distortion. For long-span high density WDM (HDWDM) systems, signal waveform distortion can be generated by linear chromatic dispersion, polarization mode dispersion, fiber nonlinearity, or their combination. In high-speed (more than 2.5 Gbit/s) time division multiplexing (TDM) optical systems, because of the short optical pulses and wide optical spectrum, the effect of complex dispersion dominates in the system performance degradation [2]. In multiwavelength WDM optical systems the inter-channel crosstalk originated by fiber nonlinearity, such as cross-phase modulation (XPM) and four-wave mixing (FWM), is a limiting factor. To maximize the WDM network capacity, the system's design and optimization have to take into account all the contributing factors - such as the channel data rate, transmission distance, signal optical power, fiber linear and nonlinear effects and of course the channel interval. In a HDWDM system the latter factor the most important for high quality solution [3].

Currently, much research in optical communications is focused on increasing the total bit rate of individual optical fiber. Most of them are grounded on novel modulation schemes for the concrete wavelength. An alternative equally valid approach for increasing transmission capacity is to scale WDM channel spacing to high-dense dimensions, while keeping the existing bit rate. Our investigation of minimal allowed channel spacing in HDWDM systems will provide recommendations for future WDM solutions, since there are neither agreed recommendations nor specifications for less than 0.4 nm channel interval [4].

### Experimental and simulation models

The overall capacity of WDM optical systems can be boosted by increasing the base transmission bit rate of each optical channel, multiplexing more channels in a HDWDM system or, preferably, by combining both of these schemes.

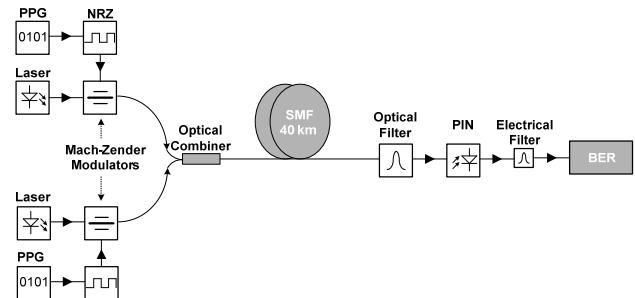


Fig. 1. Experimental model of WDM system

Our experimental transmission system of Fig. 1 employs two optical channels with external intensity modulation (IM), and non-return-to-zero (NRZ) pulse shapes. The laser is always switched on and its lightwaves are modulated via the electro-optic Mach-Zender (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 lightwaves.

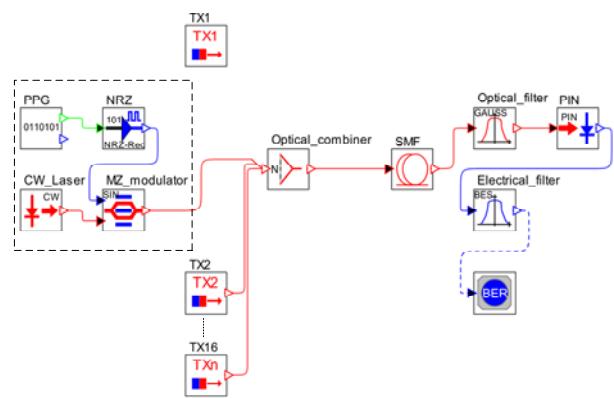


Fig. 2. Simulation model of WDM system

After the MZ modulator the signal is sent to a single mode fibre (SMF) with standard characteristics, where optical pulses are propagating over a 40 km without amplification technique. At the fibre end the 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.

According to experimental model we have created a simulation scheme in OptSim 5.0 software with the real parameters of all experimental devices Fig. 2.

## Measurement technique

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 [6]. We have used a 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 behavior for both optical and electrical components. The split step method is now used in all commercial simulation tools to perform the integration of a fiber propagation equation that can be written as

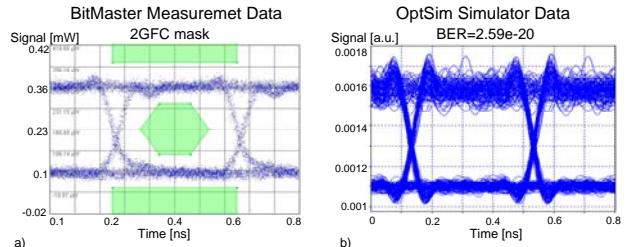
$$\frac{\partial A(t, z)}{\partial z} = \{L + N\}A(t, z), \quad (1)$$

where  $A(t, z)$  – the optical field; L – the linear operator that stands for dispersion and other linear effects; N – the operator that is responsible for all nonlinear effects. The idea is to calculate the equation over small spans of fiber  $\Delta z$  by including either a linear or a nonlinear operator. For instance, on the first span  $\Delta z$  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) method. 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 fulfill, 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 [7].

After adaptation of our experimental model in OptSim we investigate the minimal allowed channel spacing in HDWDM system by reduction the channel interval between the wavelengths. Our research is based on the evaluation such system parameter as the bit error rate (BER) through the eye diagram and estimation of optical signal spectrum.

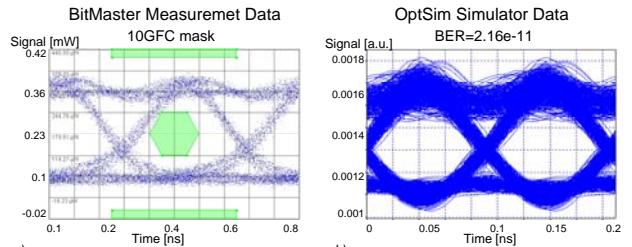
The eye diagram is a useful tool for the qualitative analysis of signal used in digital transmission. It provides at a glance evaluation of system performance and can offer insight into the nature of channel imperfections. Careful

analysis of this visual display can give a first-order approximation of signal-to-noise, clock timing jitter and skew; respectively, an eye has to be opened wide enough and spectrum diagrams should be regulars without negative multipack 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 [8].



**Fig. 3.** Measured a) and calculated b) output eye diagrams for 2.5 Gbit/s optical signals, after 40 km of SMF

OptSim simulation software calculate that parameters automatically, but for the real system eye diagram performance estimation we have to use an eye diagram masks, which are standardized by ITU-T organisation, like a 2 gigabit fibre channel (2GFC) and 10GFC masks (Fig. 3 and 4 [9, 10]).



**Fig. 4.** Measured a) and calculated b) output eye diagrams for 10 Gbit/s optical signals, after 40 km of SMF

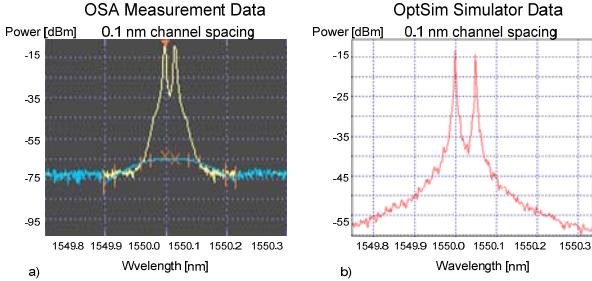
## Results and discussions

Total transmission capacity can be enhanced by increasing the number of multiplexed HDWDM channels. This can be carried out by reducing the frequency spacing between optical channels.

Together with demand for boosting total system capacity, another challenge for service carriers is to find cost-effective solutions for upgrading. These cost-effective solutions should require minimum renovation to the existing photonic and electronic sub-systems (i.e., upgrading should take place only at the transmitter and receiver ends of an optical transmission link).

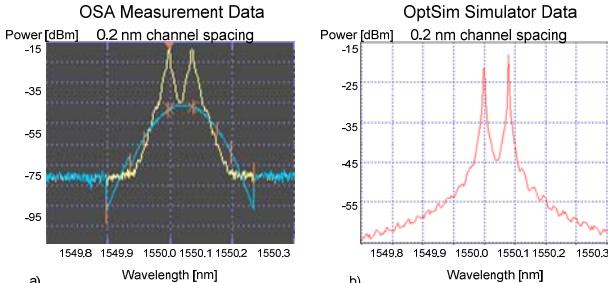
We studied experimental system data transmission over two different GHz spaced frequency channels in the wavelength range between 1549.8 nm and 1550.3 nm. The channels were shifted till effective eye diagram presented on oscilloscope and the optical signal-to-noise ratio (OSNR) was enough for good system performance. Fig. 3 and 4 presents measured and calculated optical signal quality on output of two channels HDWDM system with different bit rates. The simulation results do not much

differ from experimental model, and the optical spectrums of both measurements do not distinguished, Fig. 5 and 6. In that case we can apply more optical channels in theoretical model to reduce the channel spacing and investigate the minimal allowed reduction for HDWDM systems with different bit rates.



**Fig. 5.** Measured a) and calculated b) output spectrum for 2.5 Gbit/s optical signals, after 40 km of SMF

When reducing channel spacing for a given bit rate per channel to increase spectral efficiency in HDWDM systems, interchannel interference (ICI) and nonlinear effects become more and more significant. A major reason for signal degradation is the nonlinearity of the fiber due to high power loading at the input and signal optical amplification. For the decreasing the level of nonlinearities we do not use the optical amplification technique at all.

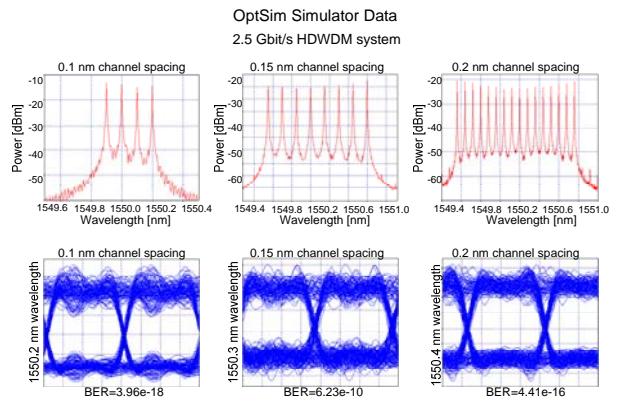


**Fig. 6.** Measured a) and calculated b) output spectrum for 10 Gbit/s optical signals, after 40 km of SMF

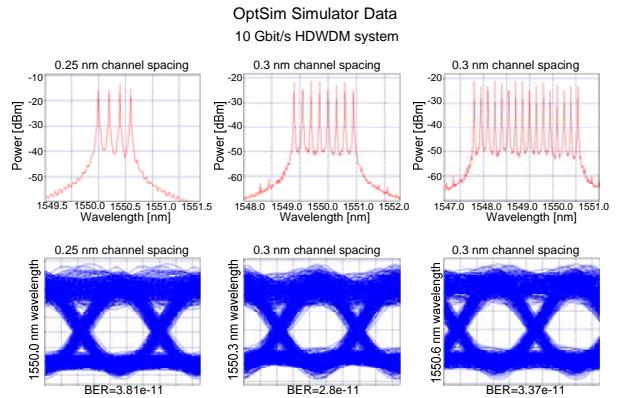
Fig. 7 shows the spectrum and eye diagrams after photo detection, for a 2.5 Gbit/s bit rate for each channel and different channel spacing. We present only successful transmission, and it can be seen that for 4 channel system the minimal channel interval is 0.1 nm or 12.5 GHz respectively. To increase the number of wavelengths till 8 and 16 the channel interval should be 18.75 GHz and 25 GHz accordingly. Only in that case the complex 2.5 Gbit/s HDWDM system transmission will be successful.

The fundamental limitation on the high speed of communications systems over the SMF are the linear chromatic and polarization mode dispersions. For the 10 Gbit/s systems the maximum transmission length, without dispersion compensation technique, would lie somewhere between 40 km and 50 km. Fig. 8 presents the transmitted 10 Gbit/s HDWDM data signal output eye diagrams and output optical signal spectrums, with different channel intervals. That solution indicates that for 4 channel 10 Gbit/s system the standard 50 GHz wavelength spacing can be reduced and the BER value still sufficient for good system performance. Also, Fig. 8 shows that the 8 and 16

channels HDWDM systems works on threshold level until wavelength spacing not less than 37.5 GHz.



**Fig. 7.** Calculated output diagrams for 2.5 Gbit/s HDWDM systems with different channel spacing, after 40 km of SMF



**Fig. 8.** Calculated output diagrams for 10 Gbit/s HDWDM systems with different channel spacing, after 40 km of SMF.

## Conclusions

HDWDM is a powerful technique for increasing the capacity of fiber optic transmission systems. It may also prove to be a crucial enabling technology for ultra-high capacity on-chip optical interconnects, as well as chip-to-chip optical interconnects in massively parallel different optical systems.

It has been shown that the BER and eye-diagram technique is a good means for evaluating the system performance that allows a WDM system to be optimized for different parameters.

In contrast to the conventional high speed approach to increasing WDM transmission capacity, we demonstrate the minimal allowed channel spacing in HDWDM systems, and provide recommendations for future WDM solutions. Our calculation have shown that, the minimal channel interval for 2.5 Gbit/s HDWDM system should be more than 0.2 nm, and for 10 Gbit/s system not less than 0.3 nm. Future optimization of the existing WDM systems will be necessary, and the minimal allowed channel spacing is only the first step for dense optical network optimization. Optical service providers will choose the favorable solution for current WDM systems, and not

always 40 Gbit/s signal per wavelength will be the best choice.

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**V. Bobrovs, G. Ivanovs. Investigation of Minimal Channel Spacing in HDWDM Systems // Electronics and Electrical Engineering. – Kaunas: Technologija, 2009. – No. 4(92). – P. 53–56.**

As WDM channel spacing continues to decrease in size, we demonstrate the minimal allowed channel spacing in HDWDM systems. According to experimental model we have created a simulation scheme in OptSim 5.0 software with the real parameters of all experimental devices. Our calculation have shown that, the minimal channel interval for 2.5 Gbit/s HDWDM system should be more than 0.2 nm, and for 10 Gbit/s system not less than 0.3 nm. These results open up new possibilities for HDWDM networks while pointing to new potential for management of optical spectrum as well as providing a limit of achievement for channel interval at different bit rates in the fiber optical network. Ill. 8, bibl. 10 (in English; summaries in English, Russian and Lithuanian).

**В. Бобровс, Г. Ивановс. Исследование минимального канального интервала в HDWDM системах // Электроника и электротехника. – Каунас: Технология, 2009. – № 4(92). – С. 53–56.**

С уменьшением канального интервала в WDM системах, демонстрируется минимально допустимый интервал в HDWDM системах. В соответствии с экспериментальной схемой мы создали симуляционную модель в OptSim 5.0 с реальными параметрами всех экспериментальных устройств. Наши вычисления показали, что минимальный интервал канала 2,5 Гбит/с HDWDM систем должен быть более, чем 0,2 нм, а для 10 Гбит/с систем, не менее 0,3 нм. Эти результаты открывают новые возможности для сетей HDWDM, рациональное использование оптического спектра, а также достижение предела для канального интервала на различных скоростях в волоконно-оптической сети. Ил. 8, библ. 10 (на английском языке; рефераты на английском, русском и литовском яз.).

**V. Bobrovs, G. Ivanovs. Minimalios kanalų atskirties HDWDM sistemoje tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 4(92). – P. 53–56.**

Apdrašomas minimalaus atstumo mažėjimas WDM sistemoje. Remiantis modeliavimo rezultatais ir taikant programų paketą OptSim 5.0 sudaryta eksperimentinio įrenginio realių parametrų struktūra. Skaičiavimai rodo, kad minimalus kanalo intervalas 2,5 Gbit/s HDWDM sistemoje turi būti didesnis kaip 0,2 nm, o 10 Gbit/s sistemoje – ne mažesnis kaip 0,3 nm. Šie rezultatai atveria naujas HDWDM tinklų galimybes. Il. 8, bibl. 10 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).