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Evaluation of Band-Pass Filters Influence on NRZ Signal in HDWDM Systems

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Introduction

Global Internet traffic has started growing rapidly demanding higher speed and capacity transmission [1, 2]. In order to achieve ultimate spectral efficiency, wavelength division multiplexing (WDM) channel spacing is reduced until the optical spectra of neighboring channels start to noticeably overlap. In this limit of high density WDM (HDWDM) systems, coherent crosstalk between adjacent WDM channels becomes a main source of degradation [3, 4]. The rapidly growing demand for more bandwidth at the end users, forces network carriers to provide a flexible data-optimized and transparent metropolitan network infrastructure. One of the main limitations in designing transparent metro networks is the signal degradation due to transmission through multiple optical filtering elements. This effect is particularly pronounced when transmitters with large optical bandwidth or with insufficient temperature stability are used [5, 6]. Low channel spacing and high data transmission rate sets strict requirements for WDM filter characteristics and any imperfections in their parameters, such as amplitude and phase responses, becomes critical. Understanding and distracting of those optical filter imperfections to high speed HDWDM transmission systems are of great importance [7, 8, 9].

In this paper we demonstrate performance of three different optical filter transfer functions: Lorentzian, Raised Cosine and Supergaussian, and their influence on 10 Gbit/s non-return-to-zero (NRZ) coded optical signals in HDWDM transmission systems. The effect of filter's full width half maximum (FWHM) bandwidth's influence on NRZ code format and spectral narrowing on signal quality has been studied extensively. We foresee that for 10 Gbit/s data transmission speed NRZ coded optical signal optimal filter's FWHM bandwidth level must be greater than 0.1 nm or 12.5 GHz.

Method of calculation

Our research is based on the evaluation of such an important system parameter as the bit error rate (BER) using simulation techniques incorporated in the OptSim 5.0 simulation software. In the present work, we show the amplitude and group delay characteristics for a couple of optical filters and represent their influence on NRZ signals in HDWDM systems.

The previously mentioned simulation software uses method of calculation that is based on solving a complex set of differential equations, taking into account optical and electrical noise, linear and nonlinear effects. Two ways of calculation are possible: Frequency Domain Split Step (FDSS) and Time Domain Split Step (TDSS) methods. These methods differ in linear operator L calculations: FDSS does it in frequency domain, but TDSS calculates linear operator in the time domain by calculating the convolution product in sampled time. The first method is easy to realize, but it may cause severe errors during simulation. In our simulation we used the second method, TDSS, which despite its complexity grants a precise result. The Split Step method is used in all commercial simulation tools to perform the integration of the fiber propagation equation:

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

where $A(t,z)$ – the optical field, L – linear operator that stands for dispersion and other linear effects, N – operator that is responsible for all nonlinear effects. The idea is to calculate the equation over small spans of fiber Δz by including either linear or 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 [4, 9].

Realization of the simulation scheme

Simulation scheme consists of four or eight channels, which depends on simulation setup. Authors have chosen this channel count values to evaluate influence of nonlinear optical effects (NOE): self – phase modulation (SPM), cross – phase modulation (XPM), four – wave – mixing (FWM) to used optical filters performance [7, 9].

The transmitter consists of (see Fig.1.) pseudo-random data source with 2^{31}-1 bit sequence, NRZ code former, continuous wavelength (CW) laser source and $LiNbO_3$-based external Mach Zehnder modulator (MZM). The data source produces a pseudo-random 10 Gbit/s electrical signal, which represents the information we want to transmit via optical fiber. Then we use a code former to form NRZ code from incoming pseudo-random bit sequence. The optical pulses are obtained by modulating CW laser irradiation in MZM with previously mentioned bit sequence. Then formed optical pulses are sent directly to a 40 km long standard single mode fiber (SSMF). The utilized fiber has a large core effective area 80 μm^2, attenuation α = 0.2 dB/km, nonlinear refractive coefficient n_k = 2.5·10^{-20} cm/W and dispersion 16 ps/nm/km at the reference wavelength λ = 1550 nm [9, 10]. Receiver block consists of PIN photodiode (typical sensitivity -17 dBm) and Bessel – Thomson electrical filter (4 poles, 7.5 GHz -3dB bandwidth).

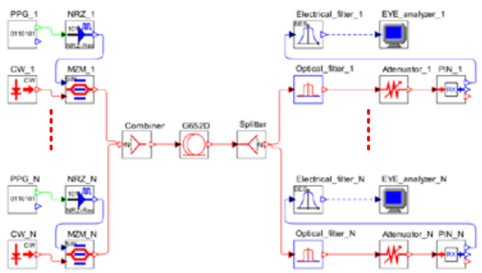

Fig. 1. Simulation scheme for HDWDM transmission realization with several optical filters

Parameters for simulation scheme are chosen based on experimental two channel scheme which is realized in our Fiber Optics Communication Systems Laboratory. Simulation scheme and measurement results were equal so applied numerical results in this paper are actual [4, 9].

Results and discussions

Optical signal by traveling through multiple optical filters experiences spectral narrowing due to temperature instability of filtering devices and light sources central frequency which could be the main factor of degradation in future all optical networks. This is because we need to find out the minimal filter's FWHM bandwidth which ensures appropriate transmitted data signal quality by ITU recommendations BER<10^{-9}. Still filters bandwidth is not the exclusive parameter which we need to be aware. Optical filters amplitude and phase transfer functions are of great importance when we transmit information via HDWDM transmission systems at minimal channel interval level between adjacent optical channels.

The main idea of our simulations is to demonstrate the effect of filter's FWHM bandwidth influence on NRZ optical signals quality. Investigation of optimal optical band-pass filters transfer functions are groundwork for realization of high speed HDWDM communication systems. The main problem is to choose appropriate optical filter amplitude transfer function for exploitation in HDWDM transmission systems. Therefore we have taken three different optical filters transfer functions (see Fig.2.)

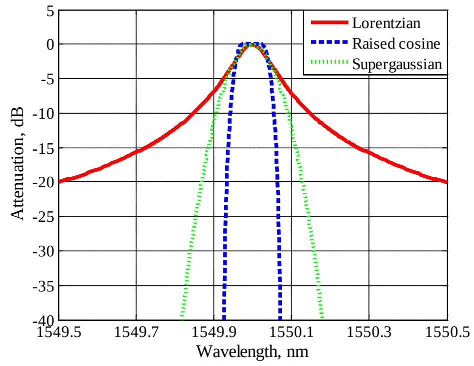

Fig.2. First order amplitude transfer functions of 0.1 nm or 12.5 GHz of different optical filters shown in inset

In addition we have chosen two values of channel count: four and eight, 10 Gbit/s NRZ coded optical signal and minimally allowed channel intervals: 0.25 nm for 4 channels and 0.3 nm for 8 channels HDWDM transmission system [4]. To realize investigation of optical filter bandwidth influence on 10 Gbit/s NRZ signal numerous simulation were made for different FWHM and insertion loss values in four and eight channel HDWDM transmission systems.

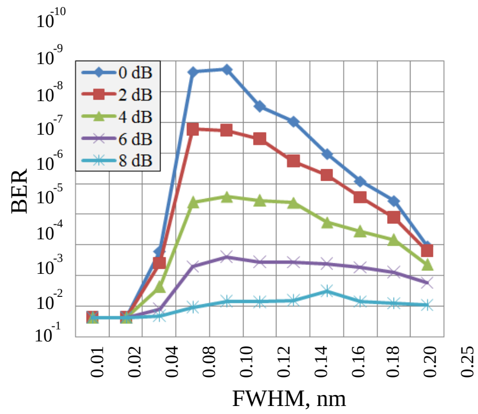

Fig. 3. Lorentzian filter case four channels 10 Gbit/s HDWDM transmission system

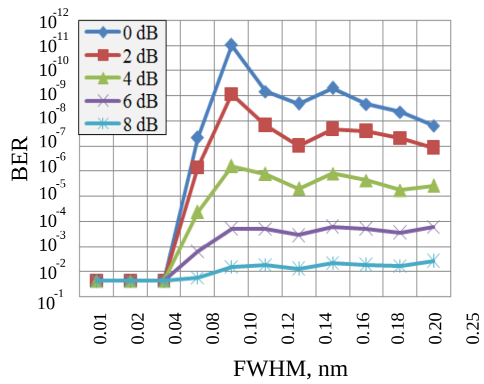

Fig. 4. Raised cosine filter case four channels 10 Gbit/s HDWDM transmission system

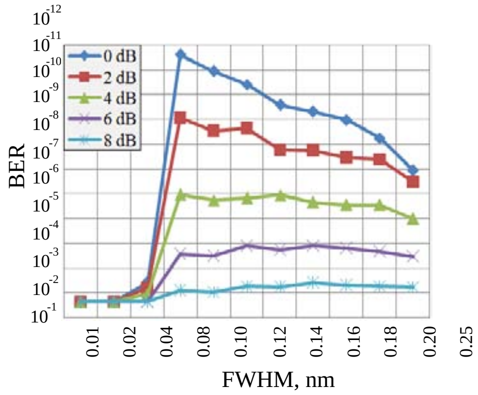

Fig. 5. Supergaussian filter case four channels 10 Gbit/s HDWDM transmission system

Fig. 3 and 4 depicts output that, optimal filters FWHM bandwidth for 4 channel HDWDM transmission system is achieved at 0.1 nm or 12.5 GHz, but in Fig. 5 this values is 0.08 nm at which BER has minimal.

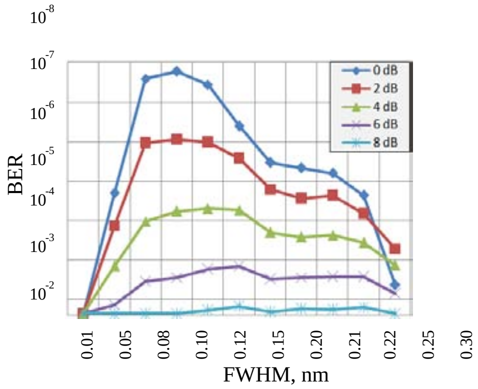

Fig. 6. Lorentzian filter case eight channels 10 Gbit/s HDWDM transmission system

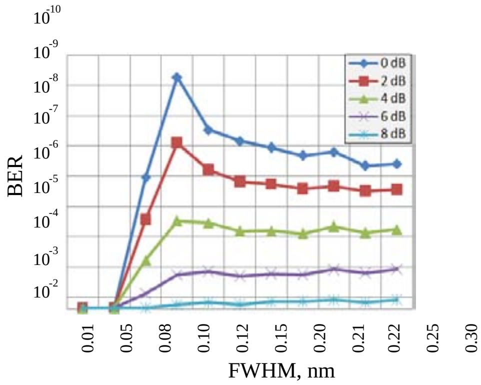

Fig. 7. Raised cosine filter case eight channels 10 Gbit/s HDWDM transmission system

As we can see from Fig.9, Raised cosine filter induce greater group delay than Supergaussian optical filter. Due to this greater group delay value at lower channel spacing the influence of SPM and XPM is greater on NRZ optical signal. By increasing channel spacing value influence NOE reduced and Raised cosine optical filters showed better results than Supergaussian optical filter for 8 channel HDWDM transmission system.

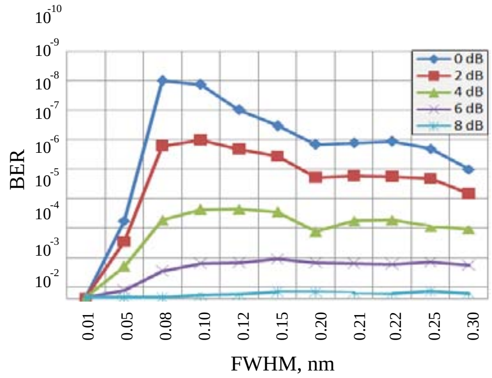

Fig. 8. Supergaussian filter case eight channels 10 Gbit/s HDWDM transmission system

As we can see from Fig. 3 and 6 Lorentzian optical filter showed the worst performance and without any success in realization of reliable 8 channel HDWDM transmission system with appropriate BER value. Best results at 8 channel HDWDM transmission system showed Raised cosine optical filter, because its amplitude transfer function is closest to an ideal filter parameters. Although at lower channel value Supergaussian optical filter showed best result. This can be explained through optical filters induced group delay to optical signal.

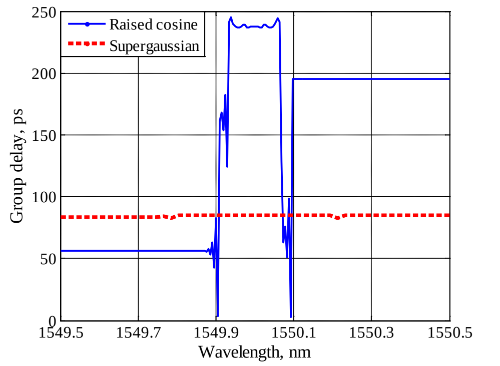

Fig. 9. Group delay as a function of wavelength shown in inset

Conclusions

As we can see from the simulations results, the evaluation of amplitude transfer functions of optical filter is of great importance, although we need to ensure that filters induced group delay is kept to the minimum. This is not a simple task when we want to achieve almost rectangular amplitude transfer function. Because at the edges of band pass filters amplitude transfer functions group delay results to be greater. Due to this we need to find out compromise between amplitude transfer function and filter induced dispersion value in high speed HDWDM transmission systems.

The results depict out that Raised cosine and Supergaussian optical filter is better for realization of multichannel HDWDM transmission systems. The worst results showed Lorentzian optical filter without any success in realization of reliable 8 channel HDWDM transmission system with appropriate BER value.

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O. Ozoliņš, G. Ivanovs. Evaluation of Band-Pass Filters Influence on NRZ Signal in HDWDM Systems // Electronics and Electrical Engineering. – Kaunas: Technologija, 2010. – No. 4(100). – P. 65–68.

In this paper we demonstrate performance of three different optical filter transfer functions: Lorentzian, Raised Cosine and Supergaussian, and their influence on non-return-to-zero (NRZ) coded optical signal in high density WDM (HDWDM) systems. The effect of filter bandwidth at -3 dB influence on NRZ and spectral narrowing on signal quality has been studied extensively. We foresee that for 10 Gbit/s data transmission speed NRZ coded optical signal optimal filter bandwidth at -3 dB level referred to full width half maximum (FWHM) value must be greater than 0.1 nm or 12.5 GHz. Ill. 9, bibl. 9 (in English; abstracts in English, Russian and Lithuanian).

О. Озолинш, Г. Ивановс. Оценка влияния полосовых фильтров на сигнал NRZ в системах HDWDM // Электроника и электротехника. – Каунас: Технология, 2010. – № 4(10). – С. 65–68.

Анализируется работа трех различных оптических фильтров: Лорентца, поднятого косинуса и супергауссовово, и их влияние на NRZ закодированного оптического сигнала в системы высокой плотности WDM (HDWDM). Эффект влиянии полосы пропускания фильтра на NRZ закодированного оптического сигнала и спектральное сужение на качестве сигнала был изучен экстенсивно. Мы предвидим, что для передачи данных на скорости 10 Бит/с, оптимальная полоса пропускания фильтра должна быть больше чем 0.1 нанометр или 12.5 ГГц. Ил. 9, библ. 9 (на английском языке; рефераты на английском, русском и литовском яз.).

O. Ozoliņš, Ģ. Ivanovs. Juostinių filtrų įtakos NRZ signalams HDWDM sistemose tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 4(100). – P. 65–68.

Atliktas optinių filtrų spartos palyginimas taikant Lorenzo, pakeltojo kosinuso ir Gauso perdavimo funkcijas. Įvertinta jų įtaka NRZ optiniam signalui didelio tankio WDM (HDWDM) sistemose. Filtro -3 dB pralaidumas turi įtakos NRZ signalo kokybei. Nustatyta, kad esant duomenų perdavimo greičiui 10 Gbit/s ir optimaliam -3 dB filtro pralaidumui, spinduliuotės spektro plotis turi būti didesnis kaip 0,1 nm, arba 12,5 GHz. Il. 9, bibl. 9 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).