

Estimation of DWDM Transmission for Broadband Access with FBG Technology

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Introduction

Recently, the number of subscribers to the optical access technology has been increasing due to advantage of high-speed Internet access and peer-to-peer services. The number of fibre-to-the-home (FTTH) subscribers in Europe has increased by 22 per cent over the past ten months. In absolute numbers, Europe reached 3.2 million FTTH subscribers. Network deployment continues to bring fibre within reach of more homes: Europe now counts 18 million FTTH homes passed, for this reason Gigabit Ethernet - Passive Optical Network (GE-PON) and Gigabit - PON (G-PON) have been already commercialized [1, 2]. Another type of access technologies: wavelength division multiplexed - PON (WDM-PON) has been considered for a long time as one of the most powerful solutions for the next-generation broadband access network and has gained increasing attention due to growing need for broadband access [3]. Still the developments on WDM-PON are in academic and experimental phase, and the standards for WDM-PON have not been established yet [4].

On the other hand, the amount of traffic is still increasing, and we can estimate that global Internet traffic will quadruple from 2009 to 2014, because it will grow at a compound annual growth rate (CAGR) of 34 per cent [5]. As a consequence, Telecom operators are forced to adapt in the near future their deployed optical fibre access systems so as to cope with these challenging advances [6]. In order to achieve greater spectral efficiency value and total information capacity and to minimize the performance degradation caused by transmission impairments, the system investigation and advancement are of great importance. Therefore it is important to evaluate dense wavelength division multiplexing (DWDM) transmission for broadband access. Moreover it is important to evaluate DWDM direct systems parameters with currently available and reasonable priced optical components. In this paper authors have measured amplitude transfer functions of fibre Bragg grating (FBG) technology optical filters with 50 GHz and 100 GHz full width half maximum (FWHM) bandwidth and have

evaluated their performance in 2.5 Gbit/s and 10 Gbit/s DWDM direct transmission system over a typical length of broadband access network.

Method of calculations

Our investigation is based on the evaluation of such system parameters as the bit error ratio (BER) and power spectral densities. This is performed employing simulation techniques incorporated in the OptSim 5.1 software tool for the design and simulation of optical transmission systems at the signal propagation level. 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 [7].

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. All commercial optical system simulation tools use the Split-step method to perform the integration of the fibre propagation equation. The form of such equation is as follows

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

where $A(t, z)$ is the optical field, L – linear operator that stands for dispersion and other linear effects, N – operator that is responsible for all nonlinear effects. The Split-Step integration algorithm works by applying separately operators to optical field over small spans of fibre. The idea is to calculate the equation over small spans of fibre Δz by including either L operator or N operator. The error deriving from separating the effects of L operator and N

operator goes to zero faster than $(\Delta z)^2$. For instance, on the first span Δz only linear effects are considered, on the second – only nonlinear, on the third – again only linear [6–10].

Realization of simulation scheme

Simulation scheme consists of three parts: transmitter, optical fibre and receiver. Channel count of simulation scheme depends on simulation setup. Authors have chosen two, four and eight channels balancing between total capacity on one hand and physical limitations like nonlinear optical effects (NOE) on the other.

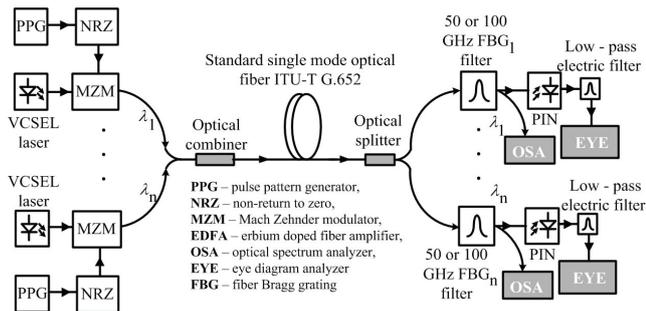


Fig. 1. Simulation scheme for DWDM direct transmission realization with FBG optical filters

The transmitter consists of (see Fig.1.) pseudo-random data source with $2^{31}-1$ bit sequence, non return to zero (NRZ) code former, continuous wavelength (CW) laser source and LiNbO_3 -based external Mach Zehnder modulator (MZM). The data source produces a pseudo-random electrical signal, which represents the information we want to transmit via optical fibre. Then we use a code former to form NRZ code from incoming pseudo-random bit sequence. The NRZ has long been the dominant code format in fibre optical transmission systems, because of a relatively low electrical bandwidth for the transmitters and receivers and its insensitivity to the laser phase noise [6]. 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 different length standard single mode fibre (SSMF). The utilized fibre has a large core effective area $80 \mu\text{m}^2$, attenuation $\alpha = 0.2 \text{ dB/km}$, nonlinear refractive coefficient $n_k = 2.5 \cdot 10^{-20} \text{ cm/W}$ and dispersion 16 ps/nm/km at the reference wavelength $\lambda = 1550 \text{ nm}$. Receiver block consists of optical filter, PIN photodiode (typical sensitivity -17 dBm) and Bessel – Thomson electrical filter (4 poles, $7.5 \text{ GHz} -3\text{dB}$ bandwidth).

Parameters for simulation scheme are chosen based on experimental DWDM direct transmission scheme which is realized in our Fibre Optics Transmission Systems Laboratory. Simulation scheme and measurement results were equal so applied numerical results in this paper are actual.

Realization of measurement scheme

Amplitude transfer function measurement scheme

(Fig.2.a.) consists of amplified spontaneous emission (ASE) light source which power spectral density was flattened with gain flattening filter (GFF), device under test (DUT): FBG combined with optical circulator, and optical spectrum analyser (OSA). In Fig.2.b we show measured amplitude transfer functions of 50 GHz and 100 GHz FWHM bandwidth FBG optical filters.

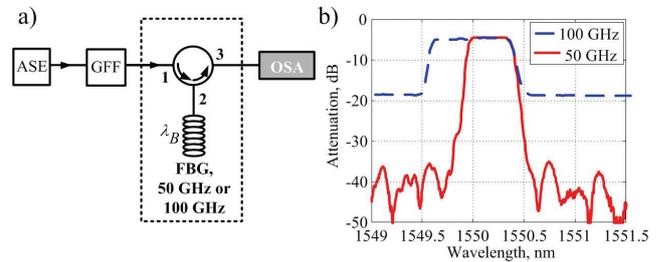


Fig. 2. Optical band-pass filter a) amplitude transfer function measurement scheme and b) FBG amplitude transfer functions with different FWHM bandwidths shown in inset

Measured FBG optical filters parameters were recorded in data file, which after simple mathematical recalculations were used in simulation scheme to build user defined optical filters and estimate their influence on DWDM transmission parameters for broadband access.

Results and discussion

The main idea of our simulations is to demonstrate FBG filters with different FWHM bandwidths influence on DWDM direct transmission system for broadband access.

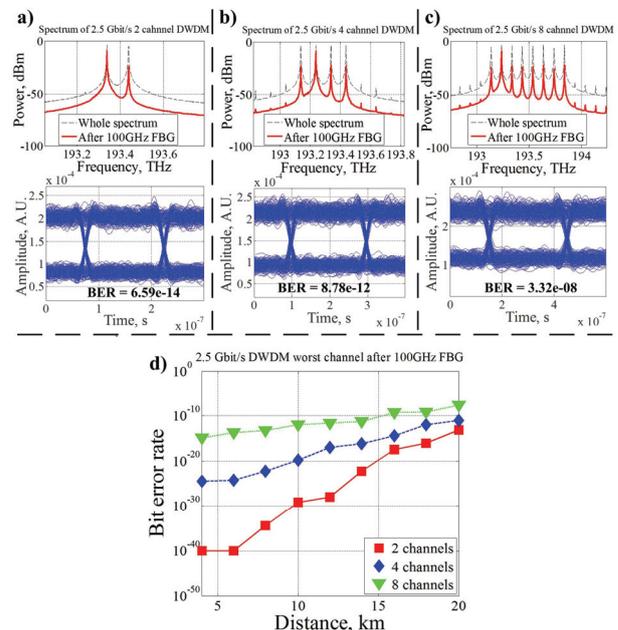


Fig. 3. Power spectral densities and eye diagrams of 2.5 Gbit/s DWDM direct a) two channels, b) four channels, c) eight channels system after 20 km of SSMF and d) BER vs. distance with 100 GHz FBG optical filter. Results obtained at the worst channel

We have measured amplitude transfer functions of two different FBG (see Fig.2.b.): with 50 GHz and 100 GHz FWHM bandwidth and have chosen appropriate

channel spacing values: 100 GHz and 50 GHz and two data transmission speeds: 2.5 Gbit/s and 10 Gbit/s what conform with 2 GbE and 10 GbE, accordingly. Fig.3.a-c. depicts out power spectral densities and eye diagrams of 2.5 Gbit/s DWDM direct transmission system with different channel count after 20 km of SSMF and Fig.3.d. shows BER dependence on distance for 100 GHz FBG. Results show that enlargement of channel count increases BER which is caused by NOE. Performance of system is degraded even more because of low adjacent channel isolation value (~ 15 dB) for 100 GHz FBG. This value is insufficient for reliable transmission realization at eight channel case. Influence of low adjacent isolation value can be seen already at the first kilometres of transmission link, but later BER values become similar due to NOE dominant influence on system parameters degradation.

Fig.4.a-c. depicts out power spectral densities and eye diagrams of 2.5 Gbit/s DWDM direct transmission system with different channel count after 20 km of SSMF and Fig.4.d. shows BER dependence on distance for 50 GHz FBG. We can see that adjacent channel isolation value (~ 30 dB) for 50 GHz FBG is sufficient to realize reliable transmission at eight channel case. In this case influence of adjacent channel caused impairments is minimized by proper optical band-pass filter parameter selection.

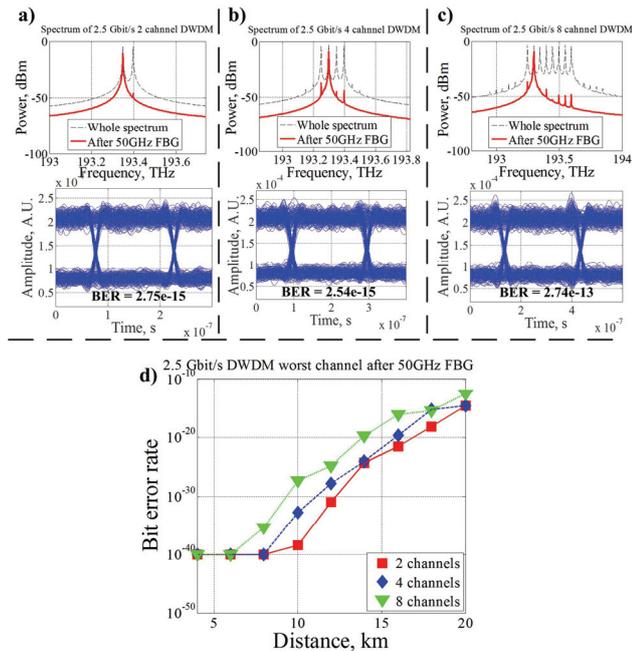


Fig. 4. Power spectral densities and eye diagrams of 2.5 Gbit/s DWDM direct a) two channels, b) four channels, c) eight channels system after 20 km of SSMF and d) BER vs. Distance with 50 GHz FBG optical filter. Results obtained at the worst channel

Fig.5-6.a-c. depicts out power spectral densities and eye diagrams of 10 Gbit/s DWDM direct transmission system with different channel count after 10 km of SSMF and Fig.5-6.d. shows BER dependence on distance for 100 GHz FBG and 50 GHz FBG, accordingly. Transmission at higher data speed is more affected by chromatic dispersion of optical fibre and total power budget of system is reduced because of greater excess loss in MZM and lower receiver sensitivity for appropriate BER threshold.

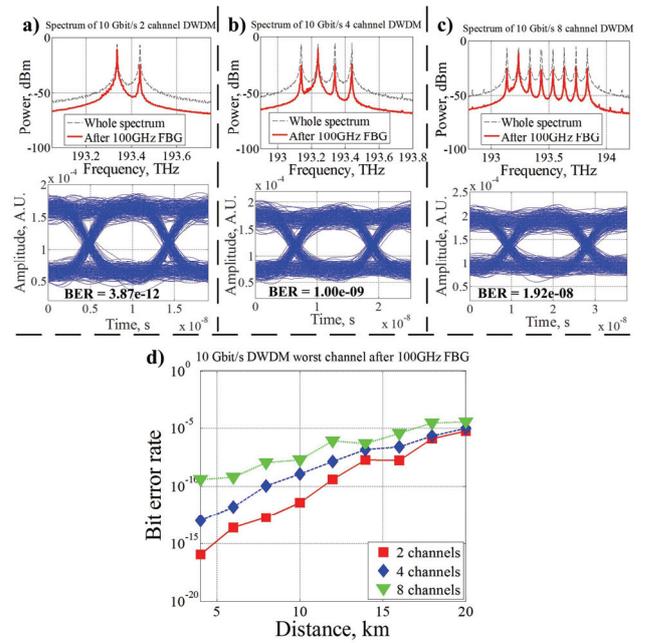


Fig. 5. Power spectral densities and eye diagrams of 10 Gbit/s DWDM direct a) two channels, b) four channels, c) eight channels system after 10 km of SSMF and d) BER vs. Distance with 100 GHz FBG optical filter. Results obtained at the worst channel

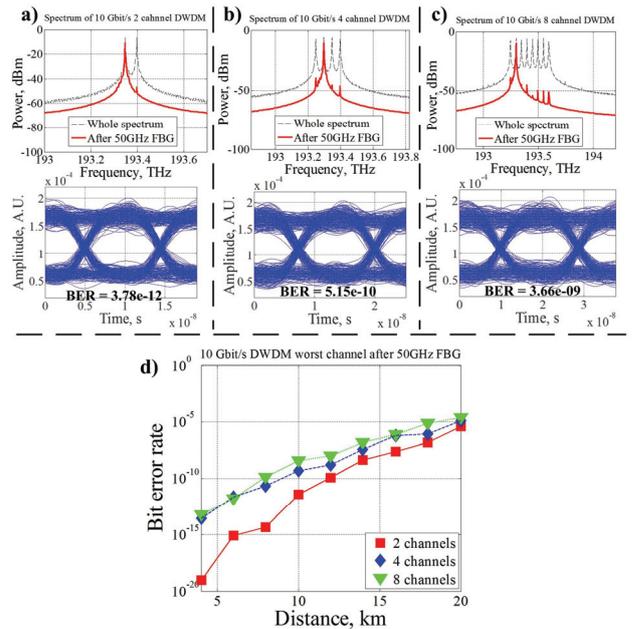


Fig. 6. Power spectral densities and eye diagrams of 10 Gbit/s DWDM direct a) two channels, b) four channels, c) eight channels system after 10 km of SSMF and d) BER vs. Distance with 50 GHz FBG optical filter. Results obtained at the worst channel

Conclusions

As we can see from the results, the proper selection of optical filter amplitude transfer functions is of great importance. In this investigation influence of adjacent channel caused impairments is minimized by proper optical band-pass filter parameter selection. Reliable transmission is realized for eight channels 2.5 Gbit/s DWDM direct with 50 GHz FBG for 20 km of SSMF and for eight channels 10 Gbit/s DWDM direct with 50 GHz FBG for reduced distance (10 km of SSMF).

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In this paper authors have measured amplitude transfer functions of FBG technology optical filters with 50 GHz and 100 GHz FWHM bandwidth and have evaluated their performance in 2.5 Gbit/s and 10 Gbit/s DWDM transmission system over a typical length of broadband access network. Reliable transmission is realized for eight channels 2.5 Gbit/s DWDM transmission system with 50 GHz FBG for 20 km of SSMF and for eight channels 10 Gbit/s DWDM transmission system with 50 GHz FBG for reduced distance (10 km of SSMF). Il. 6, bibl. 10 (in English; abstracts in English and Lithuanian).

O. Ozolins, G. Ivanovs. DWDM perdavimo sistemos įvertinimas taikant FBG technologiją // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2011. – Nr. 5(111). – P. 11–14.

Taikant FBG technologiją FWHM pralaidumui tirti esant 50 GHz ir 100 GHz dažniams, atliktas optinių filtrų perdavimo funkcijos matavimas ir skaičiavimas. Įvertintas jų našumas 2,5 Gbit/s ir 10 Gbit/s DWDM perdavimo sistemose. Nustatyta, kad, informacija patikimai perduodama taikant 8 kanalų 2,5 Gbit/s DWDM perdavimo sistemą ir FBG technologiją 20 km atstumu esant 50 GHz dažniui. Il. 6, bibl. 10 (anglų kalba; santraukos anglų ir lietuvių k.).