Transmission of High Power Sensor System and DWDM Data System in One Optical Fiber

Milan Cucka, Petr Munster, Lukas Koci, Tomas Horvath, Miloslav Filka, and Josef Vojtech

Abstract—This article deals with the possibility of employing phase sensitive OTDR (Optical Time Domain Reflectometry) into fibers with active data transmission DWDM (Dense Wavelength Division Multiplex). Due to the low backscattered signal of phase sensitive OTDR is required to generate pulses with a high intensity and short time duration. These high power pulses can cause degradation of the data transmission. By using VPIphotonics software we performed the simulations investigating the influence of phase sensitive OTDR for quality DWDM connections and we are also interested in the wavelength spacing between sensoric system and data system. In our article it was verified that phase sensitive OTDR and data transmission can be active together in one optical fiber. If both systems work very close to each other it will lead to degradation of data transmission. We have verified that data transmission may be affected if power of pulses exceed 13 dBm.

Index Terms—DWDM, Phi-OTDR, Pulse generation, Backscattered signal, Simulations, VPIphotonics.

I. INTRODUCTION

Nowadays optical sensors are used thanks to their abilities to sense high temperatures, vibrations and mechanical tension. One big advantage is accuracy of measurement and compact portable instrument packages. For example, vibration sensors are put on already existing routes and are used to track any movement around the route. Another commonly used type of optical sensors are sensors for temperature sensing due to their ability to measure high temperatures. These types of sensors can offer noncontact measurement.

Optical sensors can be divided into two groups. The first group includes extrinsic sensors with sensing outside the fiber and the second group is intrinsic that means that sensing takes place within the fiber itself. This article focuces on the influence of ϕ–OTDR (Optical Time Domain Reflectometry) sensor and their laser to the BER (Bit Error Rate) of the DWDM (Dense Wavelength Division Multiplex) system. Using same optical fibers for parallel transmission of a data and a sensing signals simultaneously is new and innovative idea.

The rest of this paper is structured as follows. Section I shortly introduce fiber optics sensors and new trends. Section II describes related work in ϕ–OTDR sensors. Section III gives an overview about DWDM system and introduces function of ϕ–OTDR sensor. Section IV and section V describes our simulation setup in VPIphotonics and discusses the results achieved in the simulation. Section VI concludes the paper and describes future work.

II. RELATED WORKS

Optical sensors based on ϕ-OTDR were first introduced in 2003 by Juan Carlos Juarez. He published his research work about optical sensors in [8]. Further, ϕ-OTDR sensors are widely used as sensors for mechanical vibrations or monitoring and securing national borders, oil and gaspipelines, military installations, structural health etc.

Many systems use an extremely narrow laser and EDFAs (Erbium Doped Fibre Amplifier). This system works on a 4 km long optical fiber with resolution of 50 m. After detection data are processed in Matlab environment. It is neccessary to filter the received signal. [9] describes the issues but does not describe using one optical fiber for the detection and for data transmission. Next issue of ϕ–OTDR is processing of received signal due to difficult filtering and analyzing. Feature extraction of time domain signals in these systems is time-consuming and may lead to inaccuracies due to noise disturbances. The recognition and speed of ϕ–OTDR systems cannot be used for online vibration monitoring systems.

The work which is called Recognition of a Phase-Sensitivity OTDR Sensing System Based on Morphologic Feature Extraction better describes this problem but does not deal with any simulation of use ϕ–OTDR systems on telecommunication routes [10]. Our article focuses on simulations in VPIphotonics software.

The authors in [11] describe amplification of the ϕ–OTDR systems, repetition rate and width of the pulses. They use a simple method using the holding beam for amplifying of pulses with low repetition rate by standard telecommunication EDFA booster. There are described three methods for ϕ–OTDR signals amplification and their verification by measurement.

These articles [12], [13], [14], [15], and [16] deal with the same topics, pulse width, duration, repetition frequency and filtering of the received signal. In comparison with other articles, our paper looks at simulation of ϕ–OTDR with DWDM system on one optical fiber.

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III. Overview of the system

A. Dense wavelength division multiplex system

Transmission systems based on DWDM are now often used to increase the transmission capacity of optical fiber or bi-directional communication. It is a combination of several wavelengths which transmit multiple lasers.

A transmitter which transmits information is modulated on each carrier frequency. A multiplexor combines each optical channel with the optical fiber. For n-channels connection one multiplexor/demultiplexor and also one modula-tor/demodulator are needed. Each channel needs light source on specific wavelength.

DWDM technology uses DFB (Distributed Feedback) laser with extremely narrow spectral line and highly selective spectral filters. These devices are very sensitive to frequency and thermal stability. This is one reason why the technology is expensive. The standard ITU-T G.694.1 specifies the individual transmission channels at the wavelength in the range from 1490 nm (200.95 THz) to 1620 nm (186.00 THz) called S, C, and L band.

DWDM grid is based on a normalized pilot frequency 193.1 Thz. The minimum spacing of each wavelength may be 0.1 nm, which uses ultra narrow DWDM. To maintain the standard it is necessary to have a spacing of 0.2 nm. To ensure proper functioning wavelength division multiplexing it is best to choose a spacing of 0.8 nm.

B. Φ–OTDR optical sensor

Commonly used optical fiber vibration sensing systems use phase sensitive optical time domain reflectometer. Φ–OTDR systems can detect and locate vibration signals by measuring the backscatter light across optical spectrum. Sensoric system commonly works with Rayleigh and Brillouin scattering. Phase sensitive OTDR uses basic single mode optical fiber which is also used for transmission. This type of sensor has been used for monitoring and safety condition of building structures, gas or oil pipeline structures. Measuring can be real-time.

Source of optical radiation sends beam to the fiber, it is short time and high powered pulse which can propagate in optical fiber. Then the part of light is continuously backscattered because of Rayleigh or Brillouin scattering. This beam is measured by processing the backscattered signal. Capturing and processing of the signal is the most used technique. This signal is sensed by the optical time domain reflectometry. Reflectometric sensing is very useful for detection vibrations and their localization. Many distributed sensors use ϕ–OTDR. Sensoric systems based on ϕ–OTDR can be used to monitor more than one vibration source along the optical fiber.

This type of sensing needs special pulses, because the backscattered signal is very low. The backscatter power may be described as [11]:

$$P_R(t) = \frac{P_i \cdot S_{\gamma R} \cdot W_0 \cdot v_g \cdot exp^{-\gamma \cdot v_g \cdot t}}{2} = P_R(0) \cdot exp^{\gamma \cdot v_g \cdot t}, \quad (1)$$

where γ is the attenuation coefficient and is equal to $1/20^{th}$

of the gradient of a plot of Rayleigh backscatter attenuation in dB, P_i is the input power, γR is the Rayleigh scattering coefficient.

The fraction of captured optical power is defined for step index fibers as [11]:

$$S = \frac{NA^2}{4n^2}, \quad (2)$$

where NA is numerical aperture and n is the fiber refractive index.

After this we can simplified the first equation as [11]:

$$P_R(t) = 7.8 \cdot E_p \cdot exp^{-\gamma \cdot v_g \cdot t} = 7.8 \cdot E_p \cdot exp^{-2\gamma \cdot v_g \cdot t}, \quad (3)$$

where we use $\gamma = 4.6 \cdot 10^{-5}$, NA = 0.12, n = 1.46.

¿From these equations we can see that backscattered power is lower than input power. For average power of 150 mW and pulse duration of 200 ns. The level of the backscattered signal is about 52 dB lower compared to the input. Standard telecommunication optical fiber has an attenuation around 0.2 dB/km.

The pulse repetition rate is dependent on the maximal length of the optical fiber, pulse repetion rate can be expressed as [9]:

$$\tau = \frac{2 \cdot L}{v} = \frac{2 \cdot L}{c/n}(s) \quad (4)$$

for our measure system duration of the pulse is [9]:

$$\tau = \frac{2 \cdot L}{c/n} = \frac{2 \cdot 40 \cdot 10^3}{3 \cdot 10^8/1.46} = 3.89 \cdot 10^{-4}(s) \quad (5)$$

where repetition rate can be calculated as [9]:

$$f = \frac{1}{\tau} = \frac{1}{3.89 \cdot 10^4} = 2.57(kHz). \quad (6)$$

IV. System description

Our system description can be divided into two parts. The first part focuses on dense wavelength division multiplex, their function and settings. The second part focuses on ϕ–OTDR system. Our designed system is depicted in Fig.1.
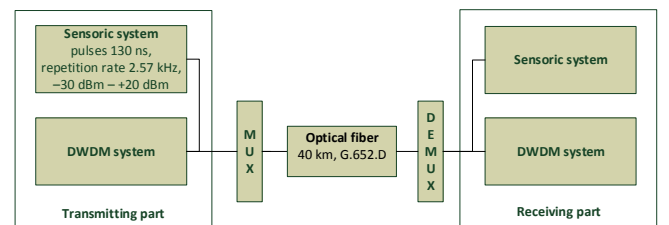

Fig. 1. Block schematic of system

In our system we use four DFB lasers for DWDM system and one DFB laser for fiber optics sensor. Laser for optic sensor has wavelengths starting at 1550.5 nm; 1551.0 nm; 1551.5 nm; 1552.0 nm; 1552.5 nm; and power performance is variable. These wavelengths are used to influence the first channel of DWDM. Sensoric system is shifted from DWDM system about 0.5 nm and the range of wavelength for sensoric

system is increased in comparison with DWDM. Coherent length of used laser for ϕ–OTDR is about 750 Hz. This length is used for 40 km optical fiber. Lasers for DWDM have wavelength of 1550 nm, 1550.8 nm, 1551.6 nm, 1552.4 nm and power 3 dBm. Data system transmits data 10 Gbit/s with BER (Bit Error Rate) about $1.91E-40$.

First of all, we simulate the optical path with 40 km optical fiber without amplifiers. We use standard telecommunication fiber G.652.D with attenuation 0.2 dB/km. In optical fibres, the attenuation is mainly caused by two physical factors, absorption and scattering losses. Absorption is caused by fibre material and scattering due to structural imperfections within the fibre. Microbending of optical fibre also contributes to the attenuation of signal.

Our simulation contains CD (Chromatic Dispersion) and PMD (Polarization Mode Dispersion) which affecting the shape and course of the transmitted signal. If we take into account these effects, our DWDM system has clear eye of the decision.

A transmitting part of DWDM system in VPIphotonics is depicted in Fig. 2. It is a module which generates pseudo random data sequence. A another block generates a sampled NRZ (Non Return to Zero) coded signal defined by a sequence of bits at its input. The signal is edited by Gaussian filter that transforms electrical input pulses into smoother output pulses. In our transmitter we use Mach-Zehnder modulator which modulates signal from generator to the DFB laser. Other blocks in Fig. 2 are for proper function of the simulation.
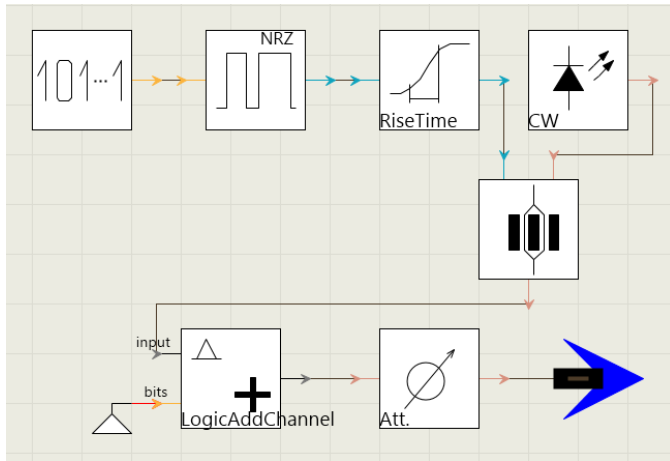

Fig. 2. Transmitting part of the DWDM system in VPIphotonics.

A receiving part of the system consists of two types of filters, Lorentzian and Bessel (optical and electrical). These types of the filters are configured by receiving wavelength. Our simulation focuses on function of DWDM system, we do not consider to watch the BER of sensor system. In our simulation we use DMUX 4 which has extension ratio about 20 dB. We want to simulate real parameters of the both systems (DWDM and ϕ–OTDR). A receiving part of the DWDM system can be seen in Fig. 3
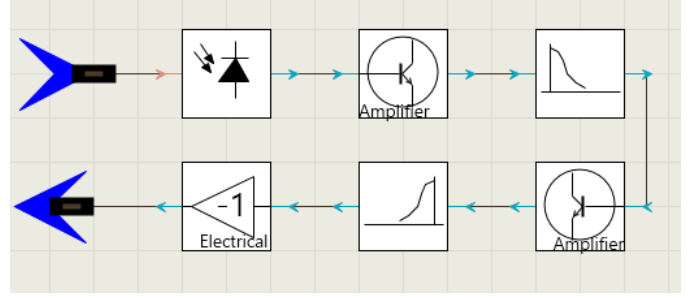

Fig. 3. Receiving part of the DWDM system in VPI photonics.

V. SIMULATION

We start at –30 dBm power of sensoric system and watch the BER of each channel of DWDM system which run at 10 Gbit/s. In our simulation we have four channels DWDM. DWDM system is shifted from sensoric system abou 1 nm. In this case the BER of all channels are about $1E-40$ and eyes of the decision are clear. When we gradually increase power of the sensoric laser, we can see in all graphs that the BER slowly decreases and eye of the decisions is not clear. It increases if the sensoric laser has the power around 0 dBm. With high power of the sensoric laser (about 13 dBm) DWDM is not able to transfer data ($1E-7$). That means data transmission is unsuccessful. In schematic Fig. 4 we can see the simulation setup in VPI photonics which is described earlier.
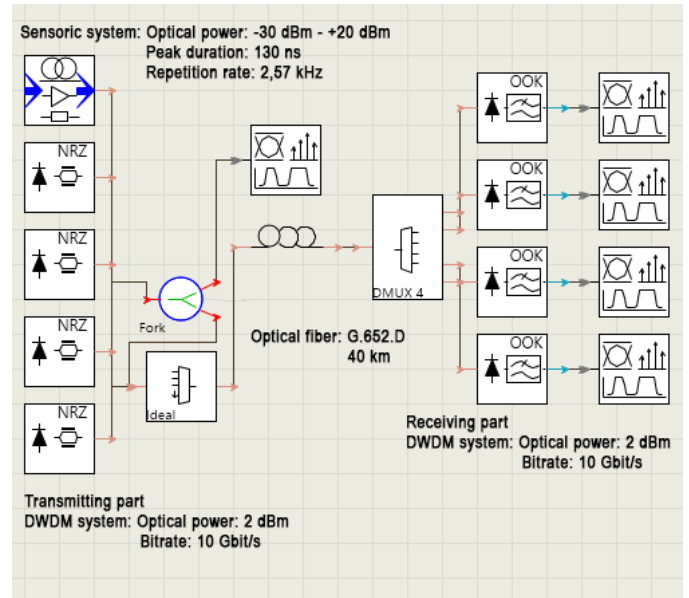

Fig. 4. Laser and DWDM system configuration in VPIphotonics.

The first results of our simulations are shown in Fig. 5. It shows the influence of the sensoric system to DWDM system shifted of 1 nm. Wavelength of the DWDM system is 1551.6 nm which is the third channel of DWDM system. We start with BER $1E-40$ and increase the power of sensoric system. Dependence shows that the BER of the third channel DWDM system gradually decreases with increasing power. All graphs also include the curve that shows BER limit of DWDM system.
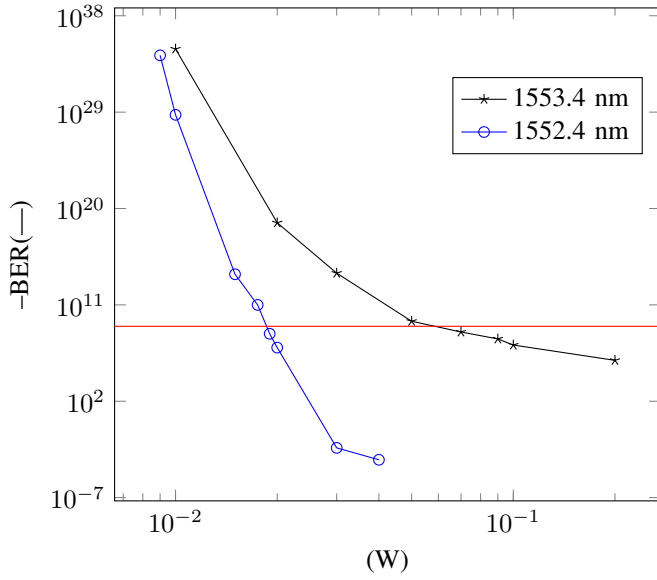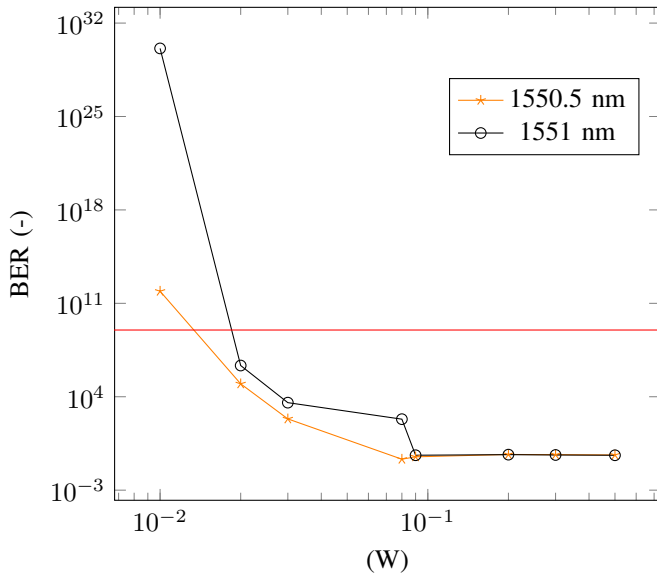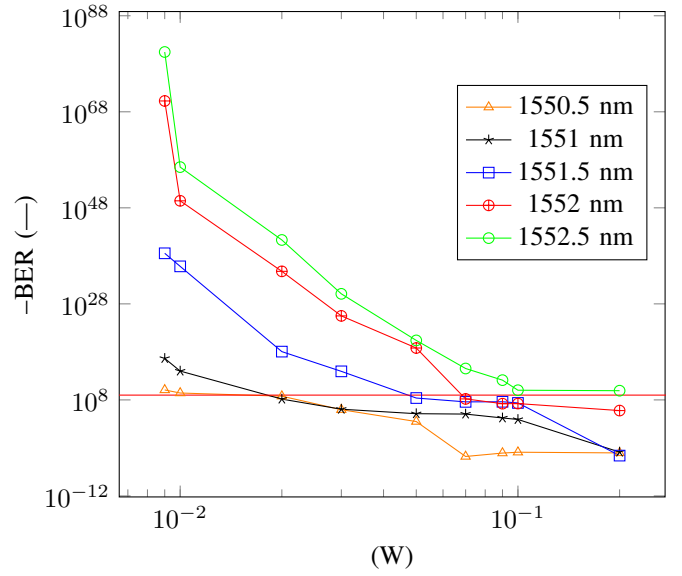
Fig. 5. Influence of the ϕ–OTDR to the DWDM system (1551.6 nm).

Fig. 7. Influence of the ϕ–OTDR to the DWDM system with variable distance.

Fig. 6 depicts the dependency of high power sensor system (about 27 dBm) to DWDM system. Distance between data system and sensoric system is 0.5 nm.

Fig. 6. Influence of the high power ϕ–OTDR to the DWDM system.

Another important part of the measurements is a difference between wavelength spacing DWDM and ϕ–OTDR that can be seen in Fig. 7. If we have small spacing, influence of ϕ–OTDR system on the first channel of DWDM system is higher than at distance of more than 2.5 nm, when system is not affected. Our designed model also includes the non-linear and linear effects. Distance between data system and sensoric system is variable. We focus on distance by 0.5 nm, 1 nm, 1.5 nm, 2 nm, 2.5 nm.

VI. CONCLUSION

Our simulation system designed in the VPI photonics software showed that it is possible to use an optical fiber for DWDM transmission and it can be also used as an optical sensor. This data transmission system is limited by maximum optical power of the used laser of the sensor system. Our simulation shows that DWDM can transmit data if the power of ϕ–OTDR is under 13 dBm. It was also verified that at distance of 2.5 nm it is not possible to affect DWDM system with ϕ–OTDR. Future work aims to use another pulse generator with different range of pulse. These generator can make pulses from 10 ns to 1000 ns with different repetition rate of the pulses. The most important future work is measurement in the function of DWDM system. This measurement confirms or disapproves our simulations.

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