PULSE GENERATOR FOR Φ–OTDR IN VPIPHOTONICS

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Abstract: The paper focuses on ϕ–OTDR (Optical Time Domain Reflectometry) systems which need short time duration and high powered pulses for proper function, because the backscattered signal is weak for proper detection. The article includes a simulation of the signal generator for ϕ–OTDR sensoric systems in simulation software. Designed generator allows to try pulses, with different time of duration, pulse repetition frequency and power. The article also includes scientific notation of backscattered signal and a short description of the used systems.

Keywords: Optical fiber sensors, Pulse generator, Simulations, VPIphotonics, Φ–OTDR.

1 INTRODUCTION

Nowadays, optical sensors are widely used for temperature sensing, preassure sensing or vibration sensing due to their physical properties. Optical sensors are resistant to high temperature, and also accuracy of the sensing vibrations and preassure is very good. These dynamic processes involve time–varying signals such as motor vibration, shift of the building structures and walking person. It is necessary to monitor not only the position but also to accurately distinguish recevied signal. That means processing the frequency of the signal from a few Hz to hundreds kHz, or tens of MHz. Classification of individual frequencies must be very precise. Commonly used systems are not able to classify vibration without complicated postprocessing and measurement cannot be real time [1].

The disadvantage of optical sensors is their high price. Thanks to new developments the price has been constantly decreasing during last years. In recent years, most optical sensors have used a combination of several sensing principles. Most commonly used are backscattered systems based on Rayleigh or Brillouin scattering combined with any interferometric method (Mach–Zehnder interferometer, Michelson interferometer) [2], [3], [4].

Huang et al. [3] describe Mach–Zehnder interferometer combined with ϕ–OTDR. System in the article can detect and localize vibration with spatial resolution of 100 m on 8 km long optical fiber. The system operates at a frequency starting from 100 Hz to 2 kHz and uses phase comparison and monitoring changes in the amplitude of the received signal. To improve spatial resolution ϕ–OTDR system is used. The received signal is processed with FFT (Fast Fourier Transform) analysis and high–speed data processing. Thanks to the complex process measurement can be real time. The main point of this article is mathematically described received signal. A description of transmitted pulses and their duration and power which uses ϕ–OTDR are missing in the paper.

The authors in [4] also describe combination of MZI (Mach–Zehnder Interferometer) and ϕ–OTDR. This sensor device requires a wide frequency response. For proper function two narrow lasers which have slightly different wavelengths are needed. The first laser is used for interferometer and the second one for ϕ–OTDR. Laser beams are separated by FBG (Fiber Bragg grating) and heterodyne detection is used. This system operates at a frequency starting from 1 Hz to 50 MHz, unfortunately there is a limited sampling rate for data capture. The spatial resolution of the sensoric system is 20 m and the system can operate on 2.5 km. Generation of the transmitted signal is better described in this article, but a detailed explanation of the system is missing.

The article describes the simulation of pulse signal generator for ϕ–OTDR. For simulation the VPIphotonics software was used. To simulate optical sensors no appropriate software have been developed yet. VPIphotonics is mainly used for simulation of data networks. Many optical elements are prepared as optical fibers, lasers, modulators. But any pulse generator for sensoric systems. The advantage of our simulation is the ability to set any pulse power level together with different duration and pulse repetition rate.

2 Φ–OTDR SENSOR

Devices which use this type of fiber sensor are applied for vibration sensing or mechanical tense sensing. The extent of these vibrations that could be compared to the acoustic wave is from 100 Hz to 17 kHz. These systems most often use Rayleigh and Brillouin scatterings. Phase sensitive OTDR sensor commonly works with a single mode optical fiber G.652.D, which is standardly used for data transmission.

Repetition rate can be calculated as follows:

$$f \leq= \frac{1}{\tau}[Hz], \tag{1}$$

explanation of time [6]:

$$\tau = \frac{2 \cdot s}{v}[s], \tag{2}$$

where we use s as the total fiber length and v is the velocity of light in an optical fiber [6]:

$$v = \frac{c}{n} = 2 \cdot 10^8 [m/s], \tag{3}$$

in this equation c is the velocity of light in the vacuum and n is the refractive index.

The pulse repetition rate is dependent on the maximal length of the optical fiber, pulse repetion rate can be expressed for simulation system as [5]:

$$\tau = \frac{2 \cdot s}{v} = \frac{2 \cdot 100 \cdot 10^3}{2 \cdot 10^8} = 1 \cdot 10^{-3} (s), \tag{4}$$

where repetition rate can be calculated:

$$f = \frac{1}{\tau} = \frac{1}{1 \cdot 10^{-3}} = 1\ (kHz). \tag{5}$$

From these equations we are able to calculate the spatial resolution for the pulse width for example of 2 μs [6]:

$$\Delta z = \frac{v \cdot T_p}{2} = \frac{2 \cdot 10^8 \cdot 2 \cdot 10^{-6}}{2} = 200\ m. \tag{6}$$

Optical pulses coupled into the fiber must be short time and high powered, which can be propagated in optical fiber. Then the part of light is continuously backscattered because of Rayleigh or Brillouin scattering. This beam is process by processing the scattered signal. Capturing and processing of the signal is the most used technique. Phase sensitive OTDR needs pulses with short time duration and high powered because the backscattered signal is very low and can be described as [5]:

$$P_R(t) = \frac{P_i \cdot S_{\gamma R} \cdot W_0 \cdot \upsilon_g \cdot exp^{-\gamma \cdot v_g \cdot t}}{2} = P_R(0) \cdot exp^{\gamma \cdot v_g \cdot t}, \quad (7)$$

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, S is the fraction of captured optical power which is defined for step index fibers as [5]:

$$S = \frac{NA^2}{4n^2}, \quad (8)$$

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

The pulse in our simulation model has inputed power 150 mW and pulse duration 2 μs. If we use equation $P_R(0)$ as is described in [5] it can be seen that backscatter power is 52 dB lower than the input power.

3 SYSTEM DESCRIPTION

The simulation is performed in the program VPIphotonics, which is a professional simulation software supports active or passive photonic integrated circuits, application of optical fiber, optical transmission systems, network applications and their subsequent analysis.

Simulation in VPIphotonics software consists of two different pulses. Every pulse has same power but different repetition rate and pulse duration. The sensoric part which is depicted in Fig. 1 uses block Rect which can generate pulses of the required parameters. Block PckBlockE simply sets the repetition rate of the generator. Other blocks (1D, Signal Analyzer) are used to track the signal. This system is in Fig. 1. Block Fork in Fig. 1 is used for proper function of simulation. This block is not nessesary to understand.

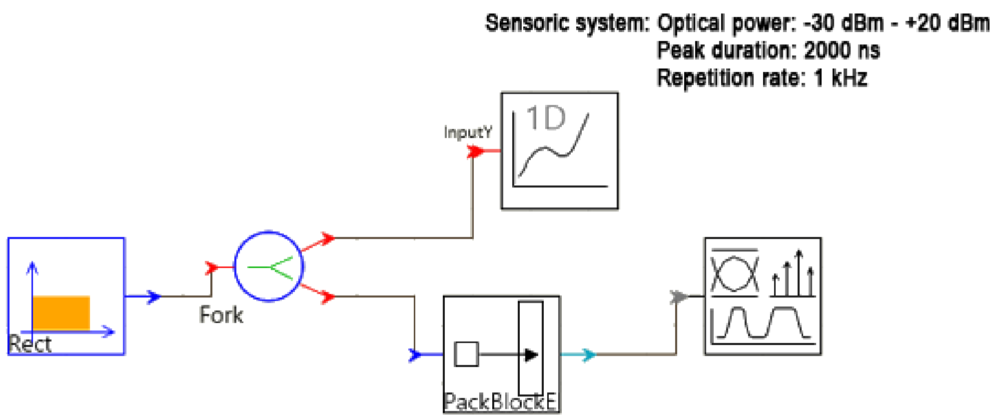

Figure 1: Simulation of pulse generator for ϕ–OTDR.

4 RESULTS AND DISCUSSION

Simulation consists of two different pulses. The first pulse has duration of 250 ns and repetition rate 0.124 ms that mean 10 kHz. The pulse have 25 m spatial resolution and can be used on optical fiber of 12.4 km long. This signal is in Fig. 2. The second pulse with duration of 2 μs and repetition rate of 1 kHz can be used with 124 km long optical fiber. The spatial resolution is 200 m. A graph in Fig. 3 shows the signal from simulation.

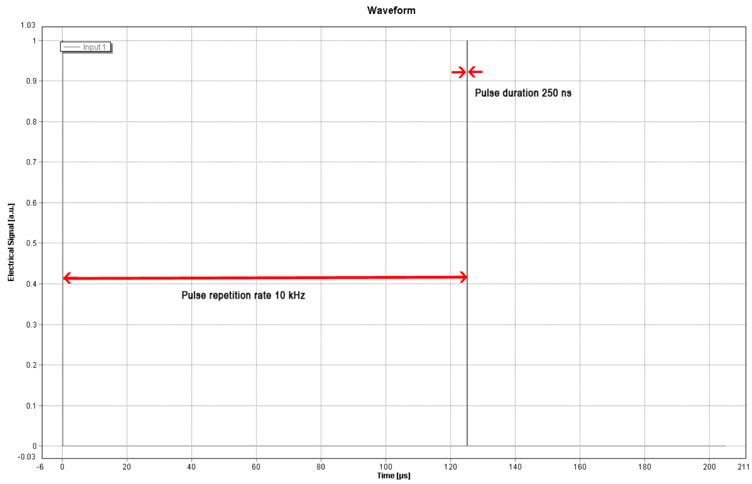

Figure 2: Signal with pulse duration of 250 ns and repetition rate of 10 kHz

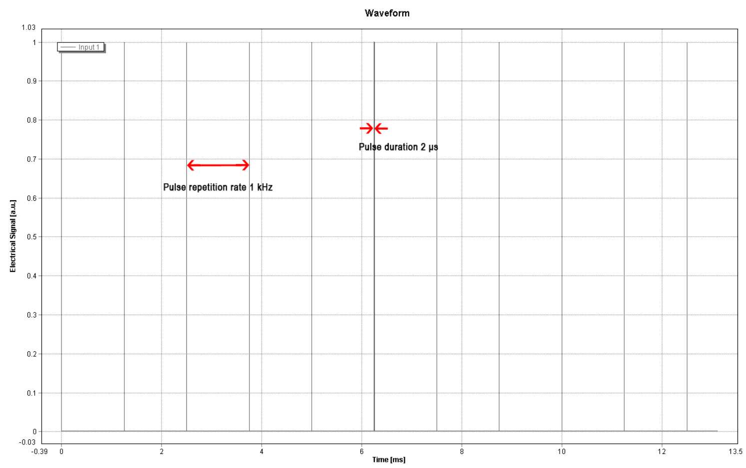

Figure 3: Signal with pulse duration of 2000 ns and repetition rate of 1 kHz

5 CONCLUSION AND FUTURE WORK

The article showed simulation setup in VPIphotonics software which describes pulse generator for ϕ–OTDR. For verification two sample situations are described. The first simulation use pulse for 12.4 km long optical fiber with spatial resolution 25 m. The second one for 124 km long optical fiber with spatial resolution 200 m. The article also includes equations which describe the calculation of pulse repetition rate frequency, pulse duration and backscattered power. To confirm the simulation it is nessesary to create pulse generator in another simulation software, for example in Simulink. For the proper results it is better to compare those two simulation softwares. The future measurements confirm the simulation.

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