Influence of Stimuled Raman Scattering on Transmitted Optical Signal in WDM System

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***Abstract*—Paper is focused on simulations behavior of signals in high-speed networks. Huge amount of transmitted information and increase in transmission speed create unwanted events in optical fiber. The main influences comprise effects such as: stimulated Raman scattering and stimulated Brillouin scattering. This paper is focused only on Raman scattering. For transmitting a signal through optical fiber one needs to select an appropriate wavelength. This is one of goals the experiment in this article. Signals were transmitted accordance with Dense Wavelength Division Multiplexing (DWDM) and spacing among channels 100GHz.**

***Keywords*—nonlinear effects; optical fiber; simulated Raman scattering;wavelength division multiple**

I. Introduction

In the past few years the requirements against transmission data rates have considerably increased. People are becoming more demanding and their efforts lead to the need of transferring as much information as possible in as short time as possible. This situation has started to address using optical fiber as a transmission medium providing high bandwidth and high transmission speeds.

Optical fibers have found application in telecommunications because they have many advantages such as resistance to electromagnetic interference, and transmitting information at multiple wavelengths and over long distances. As any transmission medium, the optical fiber also has limitations: it is fragile, sensitive to mechanical stress and bending and the many phenomena that occur in them. The environment in which the events occur distinguish linear and nonlinear phenomena.

The limitations of the optical fiber in their infancy were the dispersion and attenuation of the fiber, but these limitations are resolved with different techniques. Nonlinear effects create new obstacles to overcome. It seems to be that nonlinear phenomena are the tax for high speed transmission, the length of the transmission line, the number of wavelengths and increasing the optical power levels. These nonlinearities are key issues for limiting the amount of data that can be carried over the optical fiber.

Although the bandwidth of optical fibers is considered as a great advantage, there is a problem with effective in using the entire bandwidth effectively. This deficiency has begun solved by using WDM technology that allows transmission of multiple optical signals on a single optical fiber by using different wavelengths. WDM technology has become very popular and widely used, base on a fact that the implementation of the already built network is very simple. Installed fibers are not necessary to re-build, you only need to upgrade transmission systems. Of the currently known WDM technologies, developers took DWDM (Dense Wavelength Division Multiplexing) and CWDM (Coarse Wavelength Division Multiplexing) technology.

II. Stimulated Raman Scattering

Nonlinear effects reveal power thresholds beyond which transmission is no longer adequate. These thresholds are higher than normal power of sources, but may be reached in optically amplified and wavelength division multiplexed systems. On the other hand, they enable new applications: index change, frequency transpositions, interaction between two waves controlled by light, etc.

Raman scattering is a photon-phonon interaction, i.e. exchange of energy between optical wave and the vibrations of the material's molecular bonds.

When a pump wave goes through material, some photons transfer part of their energy $h\nu_p$ to a phonon, a particle associated with the vibration of frequency $\delta\nu$ appearing in the matter. They are then scattered with lower energy, or in other words with a higher wavelength, and constitute a Stokes wave (1) of frequency:

$$\nu_s = \nu_p - \delta\nu \qquad (1)$$

The frequency shift: $\delta\nu = \nu_p - \nu_s$ depends only on the material, and not on the wavelength of the pump. Thus, the Stokes wave spectrum is represented independently from it, versus $\delta\nu / c$ expressed in cm^{-1}. In crystals, several rays may be observed in the spectrum of this wave, corresponding to the different vibration frequencies of interatomic bonds. In disorganized environments (glass, liquids) on the other hand, a relatively large continuous spectrum can be observed, where the silica's peaks are characteristic of their composition (silica presents a peak characteristic at 490 cm^{-1}). It is a well-known method of analysis in chemistry.

Reciprocally, a few phonons will give their energy to photons, which in turn will scatter in the form of an anti-Stokes wave with (2) a frequency:

$$v_a = v_p + \delta v \text{ therefore a lower wavelength} \quad (2)$$

The anti-Stokes wave spectrum is related to the Stokes wave spectrum and greatly depends on temperature T, which creates phonons by thermal agitation (Fig. 1). The ratio between Stokes and anti-Stokes rays (3) equals:

$$\frac{\sigma_S\,(\delta v)}{\sigma_a\,(\delta v)} = \exp\frac{h\,.\delta v}{kT} \quad (3)$$

This ratio only depends on temperature, making it possible to use Raman spectrometry to know the composition and temperature of the medium. When T = 0 °K, the anti-Stokes spectrum disappears (there is no thermal agitation any longer), and the Stokes spectrum is proportional to σ_0 (δv).

During the propagation of the pump wave along an optical fiber, the Stokes wave, constantly provided with photons, is amplified according to an exponential law where the coefficient of gain is proportional to the pump wave power. When the gain becomes high, either because the pump wave is strong or because the interaction length is large, the Stokes wave empties the pump wave and creates new rays. Then Stimulated Raman Scattering (SRS) occurs, which produces a quasi-continuous spectrum over a large range of wavelengths. This "multi-Stokes emission" is used in instrumentation to generate very short pulses (less than 100 ps) with a very large spectrum [2, 8, 9].

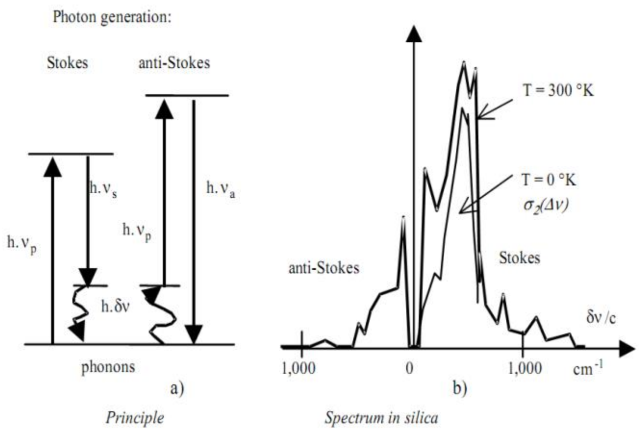

Fig. 1. Raman scattering: a) principle, b) spectrum in silica [2].

III. Dense Wavelength Division Multiplexing

Wavelength division multiplexing (WDM) is presently the most innovative technology in optical fiber communications. In the past two decades, optical communication has totally changed the way we communicate. It is a revolution that has fundamentally transformed the core of telecommunication, its basic science, its enabling technology, and its industry. By this method, capacity can be increased by using more than one optical carriers (wavelengths) on a single fiber. Therefore, adding a second transmitter and receiver to an optical fiber can double the bandwidth of that communication system. This method of increasing the capacity of an optical system has appeal for a variety of reasons. For transmission systems using a 1310 nm laser, a second laser at 1550 nm is usually added. The reason for choosing these wavelengths is that they lie in the "windows" or ranges of least attenuation.

To meet the rapid increase in the demand for multiterabit/s transmission capacities, 40 Gbps based dense wavelength division multiplexing (DWDM) is becoming the next generation in large-capacity systems. Expansion of WDM channels result in an increase in the complexity of optical network node [1].

The cost-difference between CWDM and DWDM is known to be large, favoring CWDM as the low-cost alternative. For channel counts beyond eight channels, DWDM may be a preferred technology because of its:

- Flexible upgrade.
- Scalability.
- Cost.
- Long spans.

DWDM technology is characterized by narrower channel spacing than CWDM, as defined in [ITU-T G.671]. In general, the transmitters employed in DWDM applications require a control mechanism to enable them to meet the application's frequency stability requirements, in contrast to CWDM transmitters, which are generally uncontrolled in this respect. DWDM uses frequency grid. It is a reference set of frequencies used to denote allowed nominal central frequencies that may be used for defining applications [2, 3].

The frequency grid defined by ITU G.694.1 supports a variety of fixed channel spacings ranging from 12.5GHz to 100 GHz and wider (integer multiples of 100 GHz) as well as a flexible grid. Uneven channel spacings using the fixed grids are also allowed. The current steps in channel spacing for the fixed grids have historically evolved by sub-dividing the initial 100 GHz grid [4, 5, 6].

IV. Experimental Results

In the next simulations are presented results of experiments with SRS in WDM system. Optical fiber in simulation has 100 km length. Channel spacing was set on 100 GHz and position of source pump to 1440nm wavelength. Power of laser was 600 mW. Spectrum of transmitted signal consisted of eigth channels. During experiments it was observed that spectrum of signal is sloped down to the source pump. Difference between first channel and last channel during the pumping in the backward direction is 8,7 dB. Signals with lower frequency have lower amplitude than signals with higher frequency. Due to stimulated Raman scattering signals at a higher frequency "robbed" signal with a lower frequency, consequently energy increases together with increasing frequency. In Fig. 2 is shown block diagram of used scheme.

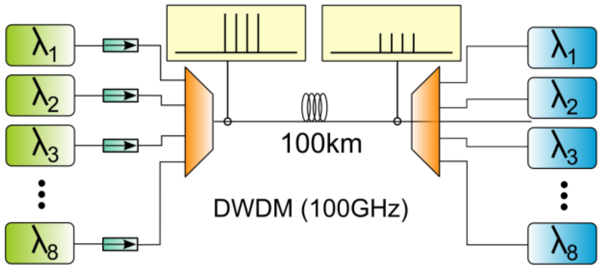

Fig. 2. Block diagram of experimental scheme.

A. Position and Output power

The position of source pump plays an important role in Raman amplification. Position of source pump at 1440 nm creates the biggest difference between the performance of input power to the fiber and power outputting from it. Mentioned difference between the input and the output power is 14 dBm at the position of source pump of 1440 nm. The power gain decreases simultaneously with the wavelength exceeding 1440 nm.

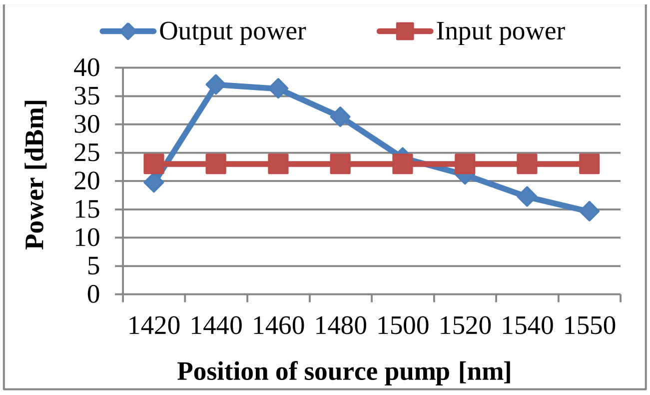

Fig. 3. Interdependency between input and output power.

Bit error rate is between $1{\cdot}10^{-11}$ and $1{\cdot}10^{-25}$. The largest error is on the first channel. Towards higher frequencies, the error rate decreases, which is caused due to the SRS, as the channels at higher frequencies have a higher performance than those at lower frequencies.

B. Length and Output power

Another simulation is focused on acquiring the relation between output power and fiber length with and also without SRS. The input power was set to a constant value (1440 nm with a power of 600 mW). In Fig. 4, there we can see how the output power without the impact of stimulated Raman scattering (SRS) rapidly declines for the optical fiber with a length of 30 km. With an increase of the fiber length over the 30 km the output power still declines, now only gradually to a value of 7 dBm obtained on the fiber length of 80 km. The same conditions were used also for monitoring the impact of SRS. The performance of output power remains above the level of 35 dBm within 80 km long fiber with a slightly decreasing trend.

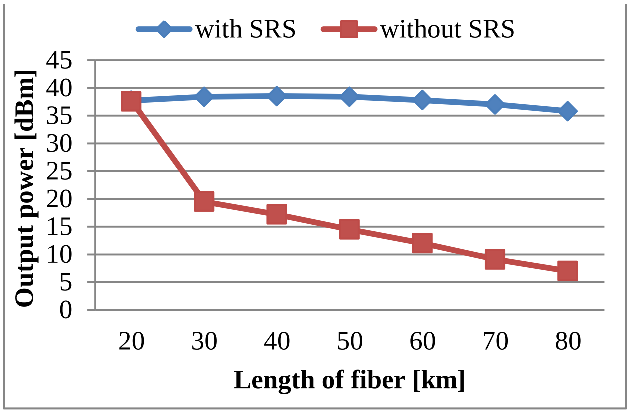

Fig. 4. The dependency of the output power on length of the fiber.

C. Change position of source pump and Output power

Dependency of output power on position and power of source pump is shown in Fig. 5. The greatest power amplification between the signal entering the fiber and exiting from the fiber can be seen in the position of source pump on the level of 1440 nm. The biggest power gain in this position of the source pump occurs on the input power level of 800 mW. The difference between the power entering into the fibers and outputting from it is 12.94 dBm. When the position of source pump was set on the power level of 1500 nm, the output power was gradually increasing up to the value of 38.28 dBm. This output is the value obtained with the input power of the source pump on the level of 1550 nm, and the difference between the power of entering into and exiting from the fiber was 6.38 dBm. The position of source pump 1540 nm, there was no amplification of the input signal. As we can see in the Fig. 5 at this position of the source pump we did not exceed the input power level.

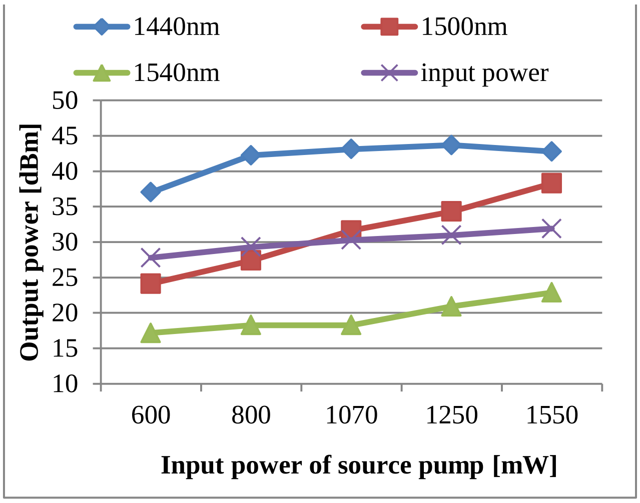

Fig. 5. Dependency of output power on position and power of source pump.

D. Bit error rate and Power of source pump

While in positions of drive pump 1540 nm avoid amplification of input signal error at that position was the lowest, and decreased below $1{\cdot}10^{-33}$ we can see in Fig. 5. but the increasing power output has deteriorated and error. If we set the position of drive pump to 1500 nm, the error rate should in the exercise of drive pump 600 mW = $1 \cdot 10^{-32}$ and gradually increased to a value of $1 \cdot 10^{-10}$ we have achieved in the execution of drive pump 1550 mW. The value of this error is still the limit tolerated error for multichannel systems. When the position of drive pump 1440 nm there was a potentiation of the largest, but the error rate is rapidly increased. The error rate should in the exercise of drive pump 600 mW = $1 \cdot 10^{-11}$, which is still above the tolerated error. When increasing the excitation power pumps to 800 mW, however, the error rate fell below the limit tolerated error rate to $7.93 \cdot 10^{-4}$ when the error rate is gradually increased to 0.02275, as we can see in Fig. 6. So at this position exciter pump it leads to inefficient amplification, resulting in the increase of error.

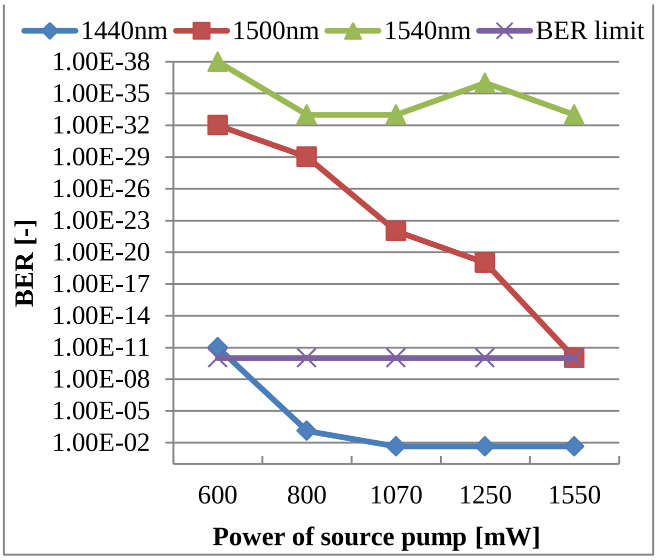

Fig. 6. Dependency BER on position and power of source pump.

V. Conclusions

The main goal of this paper to present influence of nonlinear effects in optical fiber. Nonlinear effects have very important position in field of degradation mechanisms. In experiments is possible to see options of optical fiber with and without nonlinear stimuled Raman scattering. We can be satisfied that the Raman scatter may not only have negative characteristics in the entire bandwidth. Simulations were created in programming tool OptSim. There were observed different parameters such as bit error rate BER, maximum distance of optical fiber and values of output power.

Quality of transmission depends on WDM standard. In our simulations was used standard DWDM. We used frequency grid defined by ITU G.694.1 supports a variety of fixed channel spacing equal 100 GHz. Increase number of channels in the same bandwidth results in impairment of quality. Very similar behavior is observed with increase transmission speed. When speed transmission was 2.5 – 10 Gbit/s values of BER were negligible, but with transmission speed 20 Gbit/s BER rapidly increase.

Theme of optical fibers is one of many important fields in those days. Our research team is focused on nonlinear effects and investigation also another degradation mechanisms in optical fiber.

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References

[1] G. P. Agrawal, Nonlinear Fiber Optics. Rochester, NY: Academic Press, 2013, 5th. ed.

[2] M. F. S. Ferreira, Nonlinear Effects in Optical Fibers. New Jersey: John Wiley & Sons, Inc., 2011, 1st. ed.

[3] ITU, Spectral grids for WDM applications: DWDM frequency grid, Recommendation ITU-T G.694.1, ser. Series G. International Telecommunication Union, 2012, 2nd ed.

[4] C. Decautis, Handbook of Fiber Optics Data Communication a Practical Guide to Optical Networking.2010, iSBN: 978-0-12-401673-6.

[5] S. P. Singh, R. Gangwar, and N. Singh, Nonlinear scattering effects in optical fibers. Progress In Electromagnetics Research, p. 379405, 2007.

[6] P. Banerjee, Nonlinear Optics - Theory, Numerical Modeling, and Applications. Basel, New Your: Marcel Dekker, Inc, 2004, iSBN: 0-8247-0965-9.

[7] T. J. Xia and S. Gringeri, High-Capacity Optical Transport Networks.

[8] R. Paschota, Optical Fiber Technology. Bellingham, Washington USA: SPIE Press, 2010, iSBN: 978-0-8194-8090-3.
1963, pp. 271-350.

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