Influence of Self-Phase Modulation on 8 and 16-Channel DWDM System with NRZ and Miller Coding

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***Abstract*—This article is focused on SPM (Self-Phase Modulation), which affects the signal transmission in fully optical communication systems. With the advent of WDM (Wavelength Division Multiplexing) the optical amplifiers started to be used to increase several times the optical power in optical fiber. For WDM are used weak lasers with 16 or 32 channels. A power of these channels are summed and then we work with the power in fiber about 0.5 W which is dangerous for eyes. Therefore for design of the optical network over 10 Gbit/s per 1 channel WDM, it is obligation to solve this nonlinear phenomenon. In program package OptSim was created topology 8 and 16-channel DWDM (Dense Wavelength Division Multiplexing) system according to standard ITU-T (International Telecommunication Union-Telecommunication) G.694.1 with channel spacing of 25 GHz, transmission power of 1 and 15 dBm, with transmission speed of 10 Gbit/s and two coding types to see the SPM.**

***Keywords*—BER; DWDM; OptSim; Self-Phase Modulation.**

I. INTRODUCTION

Quite a long time has expired from first successfully completed data transfer. This launched a striking development in communication technologies which are currently at a very high level. Despite advanced communication systems there is a problem with an insufficient bandwidth. It was recently partially solved with the optic cables which gradually replaced metallic lines across all networks, from the backbone networks to the access networks. Providing the most advanced services to the end customers and thus exponentially growing bandwidth requirements caused that even the already established fiber optic cables failed to provide a sufficient bandwidth mainly because of their poor utilization. This issue began to be solved with a technique called multiplexing. From the current optoelectronic systems working on the principle of multiplexing are mostly used WDM systems, in practice, primarily subsystems DWDM and CWDM (Coarse Wavelength Division Multiplex).

These systems have been deployed initially only to the backbone networks, but gradually were also deployed to the transport and metropolitan networks and it is only a matter of time when they will be implemented to the end, access networks.

The transmission reliability of such systems, the transmission of the optical fiber is affected by a number of factors which are generally divided into linear and nonlinear effects. The linear phenomena include dispersing, scattering, absorption and diffraction losses. The nonlinear effects includes the stimulated Raman scattering (SRS - Stimulated Raman Scattering), the stimulated Brillouin scattering (SBS - Stimulated Brillouin Scattering) and further phenomena such as the self-phase modulation, the cross-phase modulation (XPM - Cross-Phase Modulation) and the four wave mixing (FWM - Four Wave Mixing).

II. SELF-PHASE MODULATION

SPM is a nonlinear phenomenon caused by the interaction of light and material. Due to the optical Kerr phenomenon induced the index of refraction in the environment, the light pulse propagates in the nonlinear optical medium. It causes the dependence of the phase of the pulse on the intensity, and this results in a change of spectrum impulse [1]. In Fig. 1 is shown the effect of SPM on the signal impulse in which the frequency of the impulse with deceleration increases, and decreases with acceleration. The frequency of the pulse is in the middle linear [2, 3].

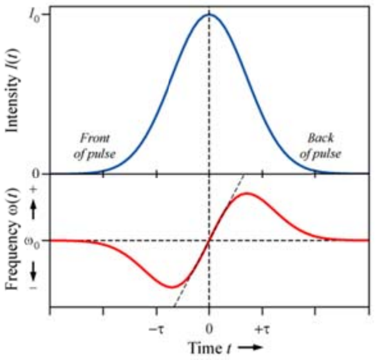

Fig.1 The impact of self-phase modulation on pulse signal [3].

In Fig. 2 is illustrated the effect of the SPM on the signal pulse. The pulse is extended in the frequency domain due to the non-linearity, whereas in the time domain the impulse remains unchanged.

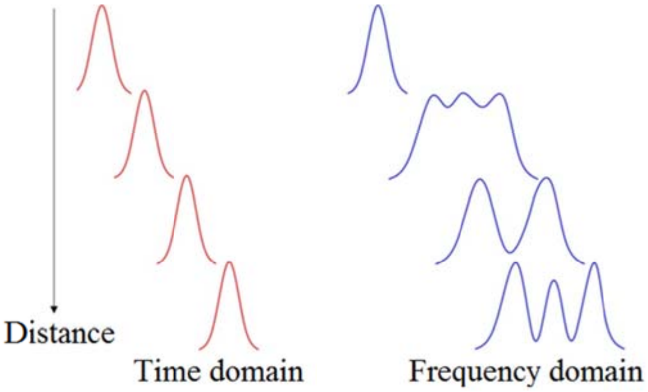

Fig.2 The increase of the pulse spectrum.

The phase changes with time in the same way as the optical signal. The different parts of the pulse go through various phase shifts due to the dependence on phase fluctuation. This results into the frequency "*chirp*" [4, 5, 6]. The primary SPM phenomenon is expanding the range of pulse. SPM phenomenon is more pronounced in systems with high transmission power because chirping effect is proportional to the transmission power of the signal [7, 9].

III. DENSE WAVELENGTH DIVISION MULTIPLEXING

DWDM is among the most advanced and most used systems in current optical communication systems. The spacing between channels is from 0.8 nm to 0.1 nm in ultra- DWDM systems with the ability to transmit several dozen channels by a single fiber.

These channels are transmitted in parallel, and without being mutually dependent which increases the transmission capacity of optical links several times. The advanced DWDM systems can on one physical link operate 96 channels, each such channel allows transmit signal speed from 2.5 to 10 Gbit/s. The type of transmitted protocol does not affect the transfer as the DWDM is a technology of the first layer. With this technology can be multiplexed most protocols, from slow to high speed such as 10 Gbit/s Ethernet. In this way can be transmitted and multiplexed together various protocols in a single fiber [8, 10].

The directive ITU-T G.694.1 "Spectral grids for WDM applications: DWDM frequency grid" defines the individual transmission channels in DWDM wavelengths in the range from 1490 nm (200.95 THz) to 1620 nm (186.00 THz) called S, C and L band [11, 12]. The DWDM grid is based on the normalized initial frequency 193.1 THz. The raster with a spacing of individual channels in the range of 100 GHz (0.8 nm), 50 GHz (0.4 nm), 25 GHz (0.2 nm) (ultra-DWDM) and 12.5 GHz (0.1 nm) unfolds from this frequency [13].

For a high quality of transmission and the correct operation it is necessary that the wavelength deviation from the nominal value does not exceed the spacing of 0.2 nm , which is a tolerance of ± 0.16 nm for a 100 GHz grid. In Fig. 3 are shown the DWDM grids.

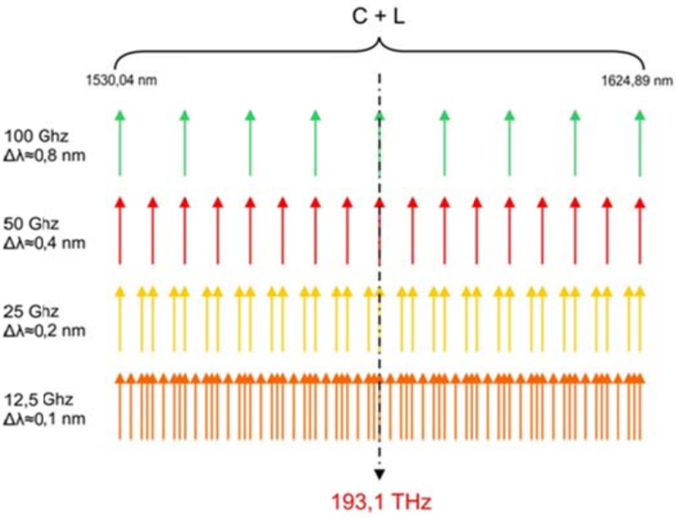

Fig.3 Channel spacing DWDM system.

IV. PROPOSED TOPOLOGY OF A SELF-PHASE MODULATION IN OPTSIM PROGRAM

Topologies consisting of 8 and 16-channels were designated according to the standard ITU-T G.694.1 with a channel spacing of 25 GHz and two types of codes (NRZ, Miller). Topologies used a single-mode optical fiber which is defined by the ITU-T G.652.D standard. The design and simulation have been made in OptSim software version 5.1 developed by Rsoft [14, 15]. The source code embedded coding was created by using Matlab.

A. The 8-Channel DWDM System

The proposed topology (Fig. 4) consists of a 8-channel DWDM system and consists of three basic parts:

- transmission units,
- network core,
- receiver units.

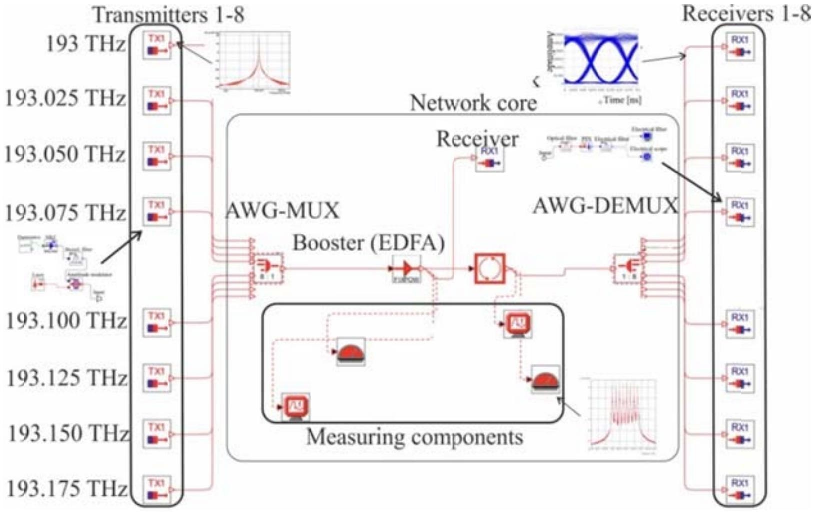

Fig.4 The proposed topology of the 8-channel DWDM system.

1) *Transmission Unit*

The topology contains two types of broadcast units consisting of a block with NRZ coding and block containing implemented Miller code from Matlab program.

The first transmitting unit (Fig. 5) is formed by source generating a logic signal, a random bit sequence. This logic signal goes to the block with NRZ coding. The coded signal goes to the modulator, the output of which is modulated signal adapted for transmission. The transmitting unit also includes an excitation laser as a radiation source. In Fig. 6 is a broadcasting unit containing the Miller code.

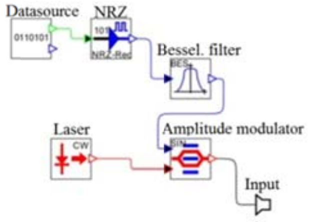

Fig.5 The transmitting unit with NRZ code.

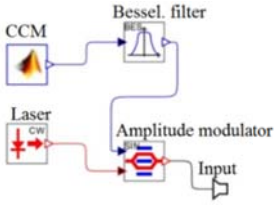

Fig.6 The transmitting unit with Miller code.

On all proposed broadcasting units were set the following basic parameters:

- transmission power of laser 1 and 15 dBm (1.25893 mW - 31.62278 mW),
- transmitting frequency of laser (193 to 193.175 GHz),
- bit rate of 10 Gbit/s per channel,
- attenuation of the amplitude modulator 3 dB,
- bandwidth of electric (low-pass) filter 10 GHz.

2) *Network Core*

The network core includes the AWG multiplexer for the multiplexing of signals in a division ratio of 8:1 which are transmitted on multiple wavelengths in a single optical fiber. The next block is an optical amplifier which is particularly important on optical fibers of long lengths. On the other side of the optical path is the AWG demultiplexer which splits the transmitted signal at 1:8 based on the wavelengths of the receivers. Fig. 7 includes a view of the network core.

The network core includes the following basic parameters:

- center frequency 193.1 THz,
- attenuation of the optical fiber 0.25 dB/km,
- the length of the optical fiber 100 km.

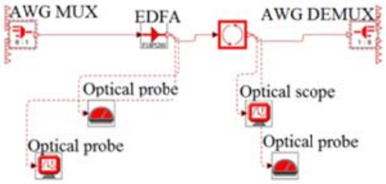

Fig.7 Network core.

3) *Receiver Unit*

The individual receiver units (Fig. 8) consist of a Gauss optical filter (band pass) which provide the desired signal based on the wavelength. It also contains a PIN photodiode which transforms the optical signal into an electrical signal. The part that works with the electrical signals from the photodiode includes electric Bessel filter (low pass) and electric node. The Bessel electric filter modifies the signal to the final shape and electrical node provides an overview of the monitored parameters.

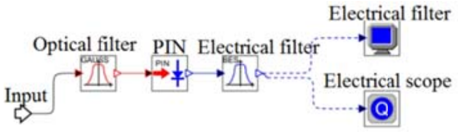

Fig.8 The receiver unit.

On all proposed receiving units were set following basic parameters:

- bandwidth of the optical filter 20 GHz,
- bandwidth of the electric (low-pass) filter 8 GHz,
- a quantum efficiency of the PIN photodiode 0.7 (70%),
- bandwidth of the PIN photodiode 40 GHz.

B. Experimental Results for 8 and 16 Channels with an Output of 1 and 15 dBm and the Channel Spacing of 25 GHz

The main objective of the simulations was to observe the self-phase modulation and its impact on the proposed optical communication DWDM system.

The impact of this phenomenon was followed by the eye diagram, the related Q factor, and the BER (Bit Error Rate). These values are among the main parameters that determine the quality of the transmitted signal.

The simulation takes place in two different scenarios, with different transmission powers. The transmission powers were increased, and the overall simulation was simulated in two powers:

- 1 dBm - 1.258943 mW,
- 15 dBm - 31.62278 mW.

The simulations were conducted at the proposed topologies in two cases. In the first case they contained different topologies in all units of the original broadcast NRZ coding and in the second case, all the transmitting units consisted of embedded Miller coding.

The following figures contain eye diagrams for specific scenarios. Each system includes simulated outputs of the four systems. The eye diagrams, and the values in the tables for the various scenarios are outputs from each receiver working on the same wavelength.

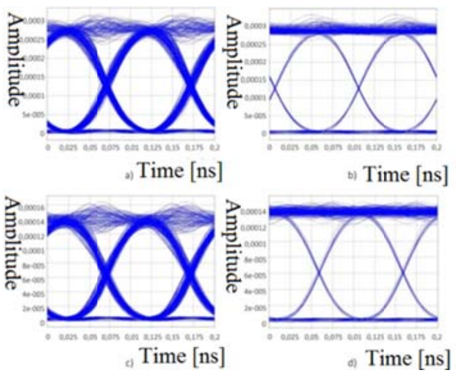

Fig.9 The eye diagrams for scenario 1 (transmit power 1dBm, channel spacing of 25 GHz): a) 8 - channel system with Miller coding, b) 8 - channel system with NRZ coding, c) 16 - channel system with Miller coding, d) 16-channel system with NRZ coding.

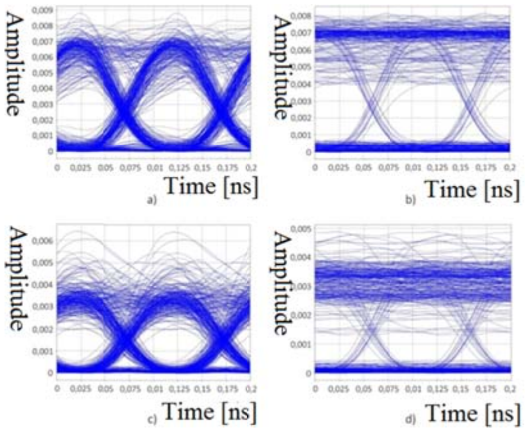

Fig.10 The eye diagrams for scenario 2 (transmit power 15dBm, channel spacing of 25 GHz): a) 8 - channel system with Miller coding, b) 8 - channel system with NRZ coding, c) 16 - channel system with Miller coding d) 16 - channel system with NRZ coding.

TABLE I. The Measured Values for 25 GHz with 1 dBm.

System	BER	Q factor	
		[lin]	*[dB]*
8 - channel (Miller)	$1x10^{-40}$	26.6858	28.525618
8 - channel (NRZ)	$1x10^{-40}$	25.0451	27.974445
16 - channel (Miller)	$1x10^{-40}$	23.5011	27.421734
16 - channel (NRZ)	$1x10^{-40}$	23.2746	27.952123

TABLE II. The measured Values for 25 GHz with 15 dBm.

System	BER	Q factor	
		[lin]	*[dB]*
8 - channel (Miller)	$5.17097x10^{-11}$	6.49184	16.247358
8 - channel (NRZ)	$2.37215x10^{-10}$	6.30811	15.997981
16 - channel (Miller)	$4.98644x10^{-7}$	4.83211	13.682726
16 - channel (NRZ)	$1.82604x10^{-6}$	4.66141	13.370352

For the first simulated scenario (no. 1) was set the transmit power of 1 dBm and the spacing of individual channels 25 GHz (Fig. 9). For these values, the SPM phenomenon is practically not shown as it can be seen in Fig. 9 where the eye diagrams for this scenario have a smooth course. It is also evident from the measured values of the parameter BER where each of the systems has an error rate of $1x10^{-40}$, the best possible value. In Fig. 11 is shown a sample of the optical spectrum for the 16-channel system with Miller coding and the eye diagram is in Fig. 9.c. Looking at the spectrum of the optical signal, the pulse signal at the output has the same course as the input pulse signal. Therefore it declares that the SPM phenomenon is at this value of transmit power essentially almost negligible. The optical spectrum in Fig. 11 is visible only for the red course which characterizes the spectrum of the signal at the output after passing the optical fiber. For this transmission power is the SPM phenomenon essentially negligible. The green course of the optical spectrum of the signal characterizes the input pulse completely covered with the red course. TABLE. I contains the measured values of the BER parameters and the Q factor for scenario 1.

For both images of the optical spectrum in the scenario 1 and 2 is true that the green progress indicates the optical spectrum of the signal at the input and the red indicates the progress of the optical spectrum of the signal at the output.

For the simulated scenario (no. 2) was set the transmit power 15 dBm and the channel spacing of 25 GHz. In the scenario 2 shown in Fig. 10 there is visible the big impact of the SPM on the eye diagrams. The eye diagrams in this scenario have quite degraded course, resulting into the values associated with this scenario in TABLE. II. The bit error rates are for the 8-channel system within the acceptable values but the BER parameter cannot theoretically reach a value less than 10^{-9} and the bit error rate of these systems is just above the threshold, which may not be sufficient for the reliable transfer. In Fig. 12, the optical spectrum of the 16-channel system with Miller coding is with a major expansion of the pulse output compare to the input phenomenon caused by the SPM.

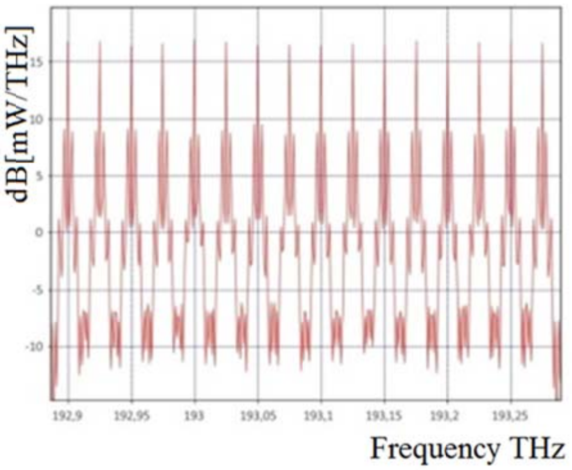

Fig.11 The optical spectrum signal of the 16-channel system with Miller coding (scenario 1).

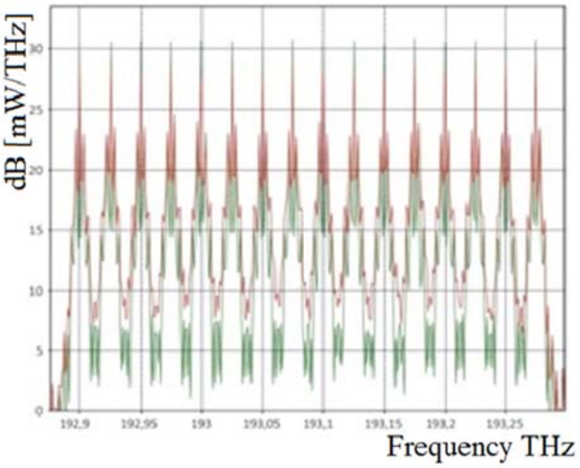

Fig.12 The optical spectrum signal of the 16-channel system with Miller coding (scenario 2).

V. CONCLUSION

Overall, there were simulated two different scenarios in which the transmission power was increased. The aim of this article was to create the DWDM topology for monitoring a self-phase modulation and the comparison of two different codes. From the results of each scenario it was clear that the implementation of the Miller coding has made slightly better results compare to the original NRZ coding.

The impact of the self-phase modulation was always a little more present in the system with the NRZ coding. In most cases, the Miller coding achieved better results by one to two orders of magnitude. By performing the simulations, it was verified that the SPM impact on the optical communication system grows linearly with increasing transmission power. The SPM phenomenon was reflected in the values of the transmission power of 15 dBm compared to the transmit power of 1dBm, when the SPM was completely negligible for the system.

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REFERENCES

[1] G.P. Agrawal, R.-J. Essiambre, ”Nonlinear limits of SDM transmission”, (2014) Proceedings - 2014 Summer Topicals Meeting Series, SUM 2014, art. no. 6903044, pp. 174-175.

[2] A. Udalcovs, V. Bobrovs, J. Porins , "Evaluation of SPM-induced optical signal distortions in ultra-dense mixed-WDM system," Future Generation Communication Technology (FGCT), 2012 International Conference on , vol. 180,no. 184, Dec. 2012, pp. 12-14.

[3] G.P.Agrawal, ”Nonlinear Fiber Optics (Fifth Edition)”, The Institute of Optics University of Rochester, New York, 2013, ISBN: 978-0-12397-023-7, 621 pp.

[4] ARCHIVED- Optical Frequency Comb. V National Research Council Canada. [online] 24. 2. 2010. [cit. 28. 09. 2015]. Dostupné na internete: http://archive.nrc- cnrc.gc.ca/eng/projects/inms/optical-comb.html.

[5] R. Ramaswami, K.N. Sivarajan, G.H.Sasaki, ”Optical Network”, A practical perspective third edition,ISBN: 978-0-12374092-2, 2010, 845.pp.

[6] Dudley, J.M., Genty, G.: „Supercontinuum light “ [online], 2013, pp. 1-11, cit. [28.09.2015]. Available on: https://hal.archives-ouvertes.fr/file/index/docid/905994/filename/Supercontinuum_light_2013_preprint.pdf.

[7] D. R. Anderson.; L. Johnson.; F. G. Bell.,” Troubleshooting Optical Fiber Networks: Understanding and Using Your Optical Time-Domain Reflectometer”, 525 B Street, Suite 1900, San Diego, California 92101-4495,USA, 2004 , ISBN:0-12-0586614, 433pp.

[8] K. Thyagarajan, A. Ghatak, ”FIBER OPTIC ESSENTIALS”, ISBN 978-0-470-09742-7, 2007 ,John Wiley & Sons, Inc. Hoboken New Jersey, 239 pp.

[9] S. F. M. Ferreira, “Nonlinear effects in optical fiber “, ISBN 978-0-470-46466-3,2011, 376 pp.

[10] T. Ivaniga, L. Ovseník, J. Turán, "Experimental model of Passive Optical Network Technical University of Kosice," in Carpathian Control Conference (ICCC), 2015 16th International , vol., no., pp.186-189, 27-30 May 2015.

[11] G.694.1 : Spectral grids for WDM applications: DWDM frequency grid. [online], 02.06.2002, cit. [23.09.2015]. Available on internete: https://www.itu.int/rec/T-REC-G.694.1-200206-S/en.

[12] F. Pope, K. Wellington, G. Keiser, "Bit-error-rate measurements in a WDM network," Military Communications Conference, MILCOM '95, vol.3, no.8, 1995, pp.1284-1287.

[13] M. S. Islam, S.M.M. Rahman, S.M. Masum, S. Parveen, S. Rafique, "DWDM technology: implementation on a unidirectional system through algorithmic approach," Parallel and Distributed Computing, Applications and Technologies. PDCAT'2003. Proceedings of the Fourth International Conference, 2003, pp.282-285.

[14] Rsoft Design Group,Inc: “Manual of optsim Models Refernce Volume 1 Sample Mode”, 2009, 543 pp.

[15] RSoft Design Group, Inc: “User Guide”, 2009, 441 pp.

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