

MODELING OF NEGATIVE INFLUENCES AT THE SIGNAL TRANSMISSION IN THE OPTICAL MEDIUM

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1. Introduction

Nowadays, an interest in the signal transmission through optical fibers rapidly increases due to the transmission bandwidth. The increasing of optical high-speed data rates in transmission systems leads to limitations caused by linear and nonlinear effects. Each nonlinear effect limits different part of optical signals (e.g. amplitude, phase, frequency and polarization). It is necessary to examine above all negative influences arising in the optical environment and their influences on different modulation techniques for achieving desired signal transmission parameters. The simulation gives transmission boundaries of advanced signal processing techniques for the considered optical system and allows comparing all the solutions before their deployments in real optical transmission paths. This paper presents features and ways for modeling of negative effects using MATLAB Simulation tools.

First, the paper introduces detailed characteristics of nonlinear effects presented in the optical transmission medium. Also, created block schemes for particular nonlinear effects are prepared for including into the model of optical transmission paths. Then, the simulation of negative influences at the signal transmission is shown for the noncoherent OOK modulated signal via the environment of a standard single mode fiber.

2. Characteristics of nonlinearities in the optical transmission medium

The optical transmission medium represents a complex frequency dependent system that consists of linear and nonlinear effects. The attenuation and the dispersion effect represents linear effects arising in the optical transmission medium, where an attenuation decreases the power of the transmitted signal and a dispersion broadens the signal in the time and shifts its phase. Both effects are major limitation factors for the optical transmission. The attenuation can be suppressed using optical Raman or Erbium Doped Fiber Amplifiers. The dispersion is much more difficult to compress. The Chromatic Dispersion can be neglected using an electric compensator or using coherent systems such as BPSK or QPSK modulation techniques. However, the Polarization Mode Dispersion has a stochastic character and therefore it represents a limitation for higher data rate optical transmission systems. More detailed analysis and design is shown in [1].

The nonlinear effects play an important role especially in the long haul optical signal transmission. We can classify nonlinear effects by a following way:

- *Kerr nonlinearities* are self-induced effects, where the phase velocity of the pulse depending on the pulse's own intensity. The Kerr effect describes a change in the fiber refractive index due to electrical perturbations. Due to the Kerr effect, we are able to describe FWM, SPM and XPM effects,
- *Scattering nonlinearities* occur due to a photon inelastic scattering to lower energy photons. The pulse energy is transferred to another wave with a different wavelength.

2.1 The Four-Wave Mixing effect

The Four-Wave Mixing FWM effect represents a parametric interaction among waves satisfying a particular phase relationship called the phase matching. This nonlinear effect occurs only in systems that carry more wavelengths through the optical fiber and it is classified as a third-order distortion phenomenon. The nonlinear interaction generates new frequency components of the material polarization vector, which can interfere with input fields if a phase matching condition is obtain. Frequency components that directly overlap with bandwidth will cause an interference with original waves. The power of new generated waves can be obtain by solving coupled propagation equations of four interacting waves, which leads to equation (1) that mainly depends on the power of neighbor channels, the channel spacing and on the dispersion [2]. The FWM block is shown in fig. 1.

$$A_k^2 = 4\eta\gamma^2 d_e^2 L_e^2 A_1^2 A_2^2 A_3^2 e^{-\alpha l} \quad (1)$$

where factor η is the FWM efficiency, γ is the nonlinear coefficient, L_e is the effective length, $A_1^2(z)$, $A_2^2(z)$, $A_3^2(z)$ are powers of input waves, l is the fiber length, α is the attenuation and d_e the so-called degeneracy factor (equal to 3 if the degenerative FWM is considered, 6 otherwise).

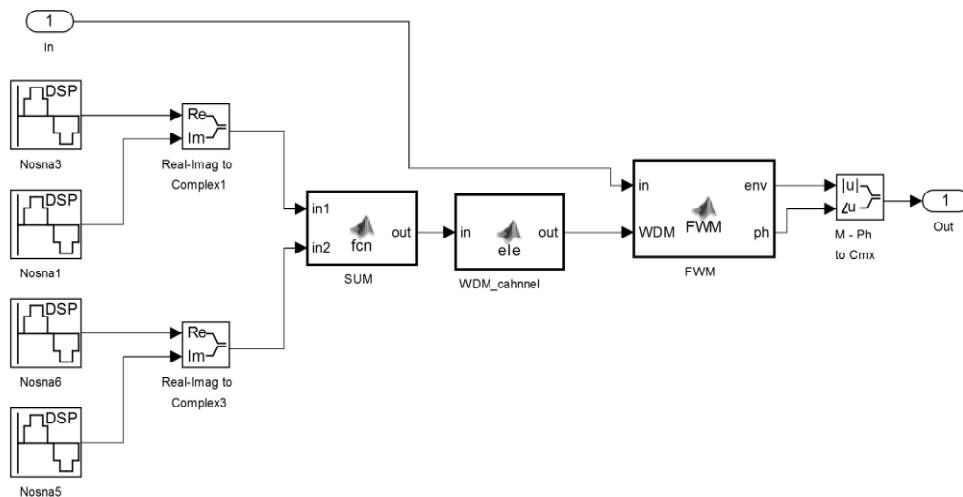


Fig.1: The FWM block.

2.2 Self-Phase and Cross-Phase Modulation effects

The Self-Phase modulation SPM and the Cross-Phase Modulation XPM effects have an important impact on high data speed communication systems that use the Dense Wavelength Division Multiplexing DWDM. The SPM effect occurs due to the Kerr effect in which the refractive index of optical fiber increases with the optical intensity decreasing the propagation speed and thus inducts the nonlinear phase shift. The XPM effect is very similar to the SPM in which the intensity from different wavelength channels changes the signal phase and thus the XPM occurs only in WDM systems. In fact, the XPM converts power fluctuations in a particular wavelength channel to phase fluctuations in other co-propagating channels [3]. Both, SPM and XPM effects results to spectral broadening and distortion of the pulse shape. The spectral broadening can be described by equation (2) and the phase shift by equation (3).

$$\omega' = \omega_0 + \frac{d\phi}{dt} \quad (2)$$

where ω' is the signal frequency influenced with the SPM effect, ω_0 is the initial signal frequency

$$\Delta\varphi_i = \frac{2\pi\overline{n_2z}}{\lambda} \left[I_i(t) + 2 \sum_{i \neq j} I_j(t) \right] \quad (3)$$

where the first term in bracket represents the SPM effect and the second term represents the XPM effect.

In the equation (3), the factor 2 has its origin in a form of the nonlinear susceptibility and represents the XPM twice as effective as the SPM for the same power amount. The XPM effect affects the signal only the interacting signals superimpose in time [3,4]. The XPM effect can decrease a system performance even greater than the XPM effect, especially in case of 100 channel systems. The common SPM and XPM block is shown in fig. 2.

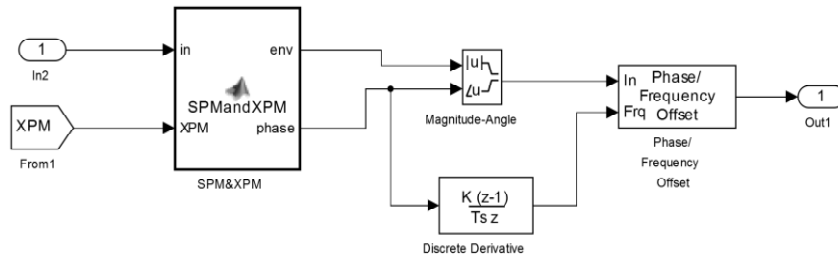


Fig.2: The common SPM and XPM block.

2.3 Stimulated Raman and Stimulated Brillouin Scattering effects

The Stimulated Brillouin Scattering SBS and Stimulated Raman Scattering SRS effects influence the intensity of the transmitted signal. In the SBS case, the acoustic wave changes the frequency of several photons that results to interference with a transmitted signal. This frequency shifted wave is propagating only in the opposite direction as the transmitted signal and the power can be described by

$$-\frac{dI_s}{dz} = +g_B I_p I_s - \alpha_s I_s \quad (4)$$

where the I_p is a pump signal, I_s represent transmitted signal intensity, g_R is stimulated Raman gain coefficient and α_s and α_p are losses of signals.

The SRS effect is similar to the SBS, were the spectral width is wide and interferes with several transmitted signals. The SRS effect propagates in both directions. Both stimulated scattering effects represent a noise in optical transmission systems [4,5]. The power of the frequency shifted wave can be described by

$$-\frac{dI_s}{dz} = +g_R I_p I_s - \alpha_s I_s \quad (5)$$

where the I_p is a pump signal, I_s represent transmitted signal intensity, g_R is stimulated Raman gain coefficient and α_s and α_p are losses of signals. A design of the common SRS, SBS and attenuation block is shown in fig. 3.

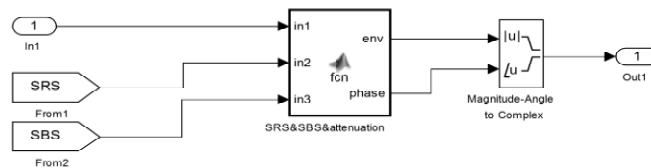


Fig.3: The common SRS, SBS and attenuation block.

3. Simulation of nonlinear effects in optical fiber

The presented simulation model comes out from the simulation model for optical communications introduced in [6-8]. A modeling is performed in the Matlab Simulink 2014a programming environment. The simulation model shows an influence of nonlinear effects on transmitted optical signals. The simulation model is designed for the Samsung single mode UltraPassTM non-zero dispersion-shifted fiber [9].

A design of the FWM effect requires utilizing of the WDM technology and thus the generation of additional wavelength channels is shown in fig. 1. These additional neighbor channels are mixed in the WDM block and driven to the FWM block. The FWM block scheme first verifies the phase matching conditions and then mixes neighbor signals using the equation (1) if phase conditions are satisfied. The influence of the FWM effect on the OOK transmitted signal is shown in fig. 4.

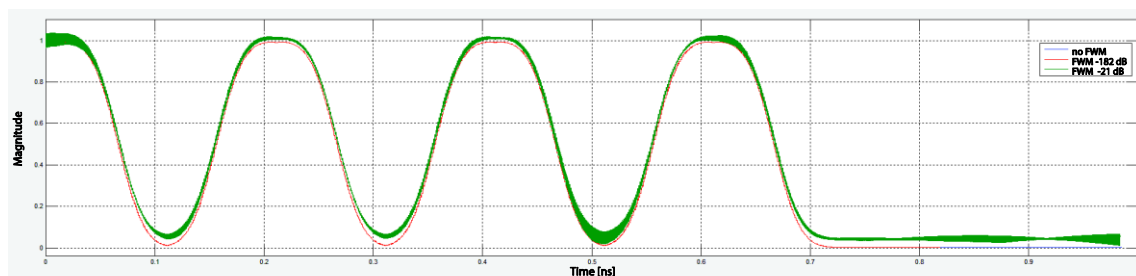


Fig.4: The OOK transmitted signal influenced by the FWM effect.

A design of the common SPM and XPM block is shown in fig. 2, where the SPM&XPM block calculates the amount of spectral broadening. Both outputs are driven to the Frequency Shifting block, where the signal is spectrally broaden. The fig. 5 shows the signal phase shift due to phase modulation effects.

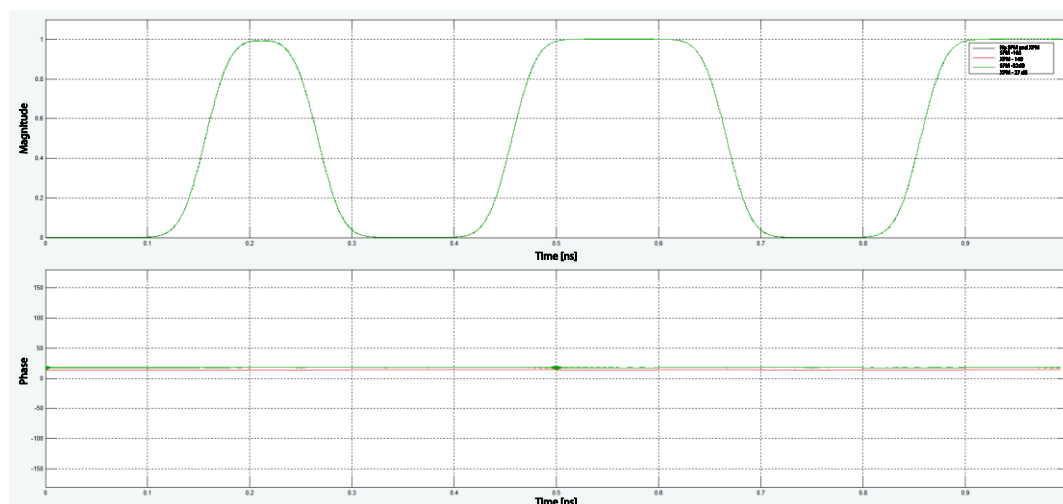


Fig.5: The OOK transmitted signal influenced by the SPM and XPM effects.

The SRS&SBS block can be designed by adding additional signal channels using a combination of two equations. These equations include the transmitted signal attenuation coefficients and therefore the common SRS, SBS and attenuation block is designed. Assuming the standard SM fiber, the SRS effect downshifts neighbor signals by about 13,2 THz with the Raman band around 5 THz and the SRS effect downshifts about 11 GHz with the Brillouin band less than 20 MHz. The influence of SRS and SBS effects together with attenuation is shown in fig. 6.

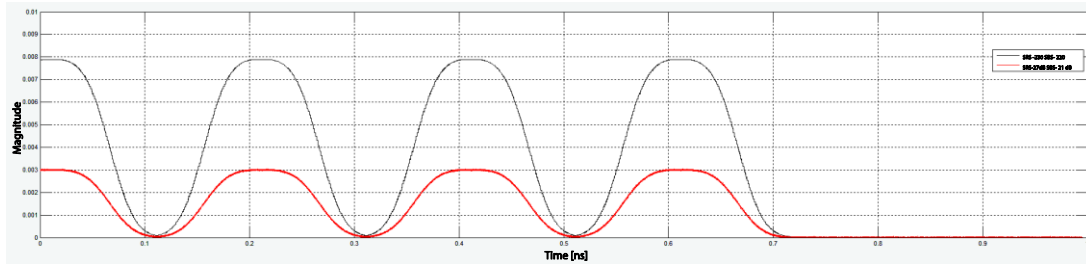


Fig.6: The OOK transmitted signal attenuated and influenced by the SRS and SBS effects.

Conclusion

This contribution analyses a modelling of nonlinear effects in the optical transmission medium. Using created specific blocks in the Matlab Simulink programming environment, we can simulate the influence of each linear and nonlinear effect on transmitted signals utilized by WDM optical systems. We present changes of the optical signal modulated with noncoherent OOK keying due to nonlinear effects arising in the transmission environment. In future analysis, we can design new and advanced combinations of high-bit rate coherent modulation formats with different encoding techniques or include optical signal amplifications into long-haul transmission paths.

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