Investigation of Cross Phase Modulation Based On Semiconductor Optical Amplifier in Nonlinear Optical Loop Mirror

Article Info

Received:4/7/2013
Accepted: 10/11/2013
Published online: 1/12/2013

Rosnahlizawati Rostam[1, a], Mohamad Halim Abd Wahid[1, b], Shamsul Amir Abdul Rais[1, c]

[1]School of Microelectronic Engineering, Universiti Malaysia Perlis, Perlis, Malaysia

[a]rosnahlizawati@gmail.com, [b]mhalim@unimap.edu.my,[c]shamsulamir@unimap.edu.my

ISSN: 2231-8860

ABSTRACT

The performance of optical transmission systems are limited by nonlinear fiber effects in cross phase modulation (XPM). The XPM has an important impact on today's high speed dense wavelength division multiplexing optical fiber communication systems. In order to obtain high conversion speed and strong nonlinearity, semiconductor optical amplifier nonlinear optical loop mirror (SOA-NOLM) is operated with large bias current and high optical powers. This paper study of the investigation of XPM on the SOA based NOLM with reference to variables SOA current, repetition rate and switching window. The SOA is a promising candidate for cascaded optical fiber systems and optical grating because of the entire fiber transmission window and the possibilities for integration and low cost. The operating conditions under which a SOA based NOLM with optical feedback can have two stables modes of operation at switching rate faster than the gain recovery rate of the SOA. Furthermore, signal induced phase shift dependence on bias current of the SOA and optimized loop parameters are also included.

Keywords: **Cross phase modulation (XPM), Semiconductor optical Amplifier (SOA), Nonlinear optical loop mirror (NOLM), All-optical switching.**

1. Introduction

Optical communication has many advantages such as lower data loss, lower cost and small lightweight size (Agrawal, 2007). The potential of optical fiber communication can be described as better than communication by copper or wireless media. In optical systems, the term nonlinearity refers to the system dependence on a power when optical beams are launched into a fiber cable. Nonlinear effect is also known as Kerr effect. It has become a

material of great importance in optical fiber based systems (Downing, 2005). A Kerr effect is the third order of nonlinearities in optical fiber interaction. Cross phase modulation (XPM) is one of Kerr effect. XPM is the signal modulation of a signal caused by an adjacent signal within the same fiber optic cable. XPM is related to the combination of dispersion and effective area. The induced phase shit is due to the walkover effect, where two pulses at different bit rates or with different group velocities walk across each other (Downing, 2005). The XPM is using nonlinear optical loop mirror (NOLM) in applications of ultrafast all optical signal processing. The NOLM has two important properties; the inherent stability of its interferometer arrangement and the intrinsically very fast response time based on the fiber nonlinearity which enables ultrafast signal processing (Downing, 2005). However its operation does not depend on the optical nonlinearity of the fiber but on the optical nonlinearity of a semiconductor optical amplifier (SOA). The SOA is used as the nonlinear material in a fiber loop, rather than the fiber itself. This has enabled the use of much shorter loops because of the much larger nonlinearity available in semiconductors than in silica fibers. Typically the length of the SOA is a few hundred microns compared with a few hundred meters of optical fiber as normally used.

2. Methodology

The NOLM used as pump driven switch is based on the XPM effect (Rogers, 2001). The XPM is the phase difference which occurs between two counter-propagating signal halves as induced by circulations power control that circulates in a loop direction (Agrawal, 1997). The signal and the control are pulsed and must be accurately synchronized in the loop since the phase shift is induced in correspondence of the control marks. Figure 1 shows the configuration of XPM based on SOA-NOLM. The major impact is a nonlinear phase shift undergone by only one of the two counter-propagating halves of the input signal, due to instantaneous power of the co-propagating control pump. In the other half of the signal, it depends on the power of the counter-propagating light.

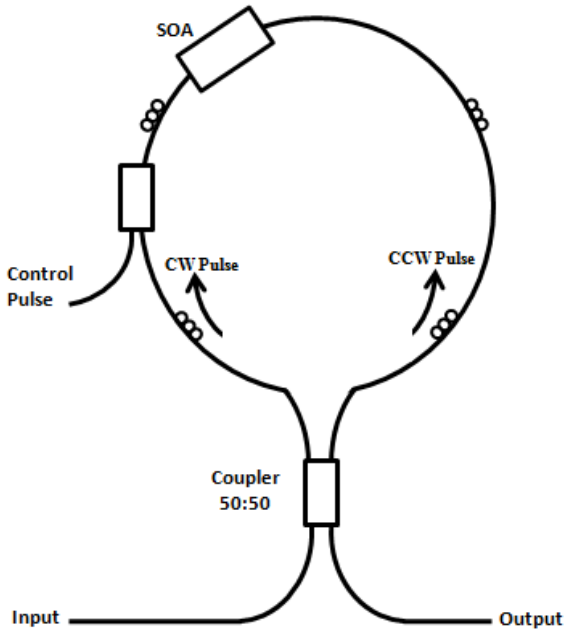

Figure 1: The XPM based on SOA in NOLM configuration

In the absence of a control signal, incoming data signals enter the fiber loop passed through SOA at different times as they counter-propagating around the loop and recombined in the 50:50 couplers at the loop base. As signals propagate around the loop in both directions seek the same medium, the data is reflected back towards the source. In the presence of control signal, switching can occur. When the control signal is injected into the loop and its power is enough and high, it saturates the SOA and changes its refractive index. As a result, a differential phase shift can be achieved between the two counter-propagating data pulses to switch the data pulses to the output port. The SOA is offset from the center position of the fiber loop and this will provide switching window duration.

From the simulation circuit in Figure 1, the basic behavior of the SOA being switched at repetition rates exceeds the SOA lifetime with the simplest rate equation model of SOA for the carrier density N (Keiser, 2000),

$$\frac{\partial N(z,t)}{\partial t} = \frac{I}{eAl} - \frac{N(z,t)}{\tau} - \frac{P(z,t)\Gamma g}{h\nu A}(N(z,t) - N_T) \tag{1}$$

where I is the effective injection current, e is the unit electric charge, l is the device length, τ is the carrier lifetime, P is the optical switching power, Γ is the mode confinement factor, g is the gain coefficient, $h\nu$ is the photon energy, A is the cross section of the active region and N_T is the carrier density at which transparency is achieved. The most important SOA longitudinal effects in long devices which run at high injection current is ignored in this simulation. The qualitative behavior in the regime considered here would be similar. In the absence of optical pumping, the equilibrium carrier density N_0 is,

$$N_0 = \frac{I\tau}{eAl} \tag{2}$$

From the Eq. (1), this may be used to express the following form

$$\frac{\partial N}{\partial t} = \frac{[N_0 - N(z,t)]}{\tau} - \frac{P(z,t)\Gamma g}{h\nu A}(N(z,t) - N_T) \tag{3}$$

The optical power P varies with distance z down the SOA according to

$$\frac{\partial P(z,t)}{\partial z} = [g\Gamma(N - N_T) - \alpha_{int}]P(z,t) \tag{4}$$

where α_{int} is the internal waveguide loss co-efficiencies. These equations explain the phase shift imparted on the two counter-propagating signal pulses in the loop by the switching pulse in the SOA. The XPM-induced coupling among multiple optical fields gives a rise to a number of interesting nonlinear effects in optical fibers. The effective mode area A_{eff} is defined by both the signal and pump pulses as

$$A_{eff} = 2\pi \cdot \frac{\left|\int \varphi_s^2 r dr\right|\left|\int \varphi_p^2 r dr\right|}{\int \varphi_s^2 \cdot \varphi_p^2 r dr} \tag{5}$$

when pulses at different wavelengths are considered, the effect of XPM depends on the relative temporal locations of those pulses. XPM is strongest when pulses completely overlap one another. The spectra of both pulses in XPM are expected to broaden and develop multiple peaks with the outermost peaks the most intense.

3. Result and Discussion

Simulated evidence of the role played by XPM based on SOA in NOLM is shown in Figure 1. The control pump wavelength is 1540 nm and the signal wavelength is 1555 nm. The XPM in SOA-NOLM is investigated by varying some parameters such as SOA's input current. The current injection into the SOA creates electron and hole carriers. When an optical signal is launched into the SOA, it experiences amplitude and phase changes because of the gain provided by the SOA and the associated changes in the refractive index. The average power is -15 dBm. The parameters varied are signal repetition rate, injection current and optical delay that governs switching window.

3.1 Signal repetition rate

In XPM simulation, three signal repetition rates are used; 2.5 Gbs^{-1} (400 ps), 5 Gbs^{-1} (200 ps) and 10 Gbs^{-1} (100 ps) while the pulse width for every repetition rate are same as in SPM simulation. The SOA current is 0.2 A and the switching window is 150 ps. Figure 2 shows the spectral broadening for 2.5 Gbs^{-1}. The output wavelength broadens 0.08 nm at power -50 dBm.

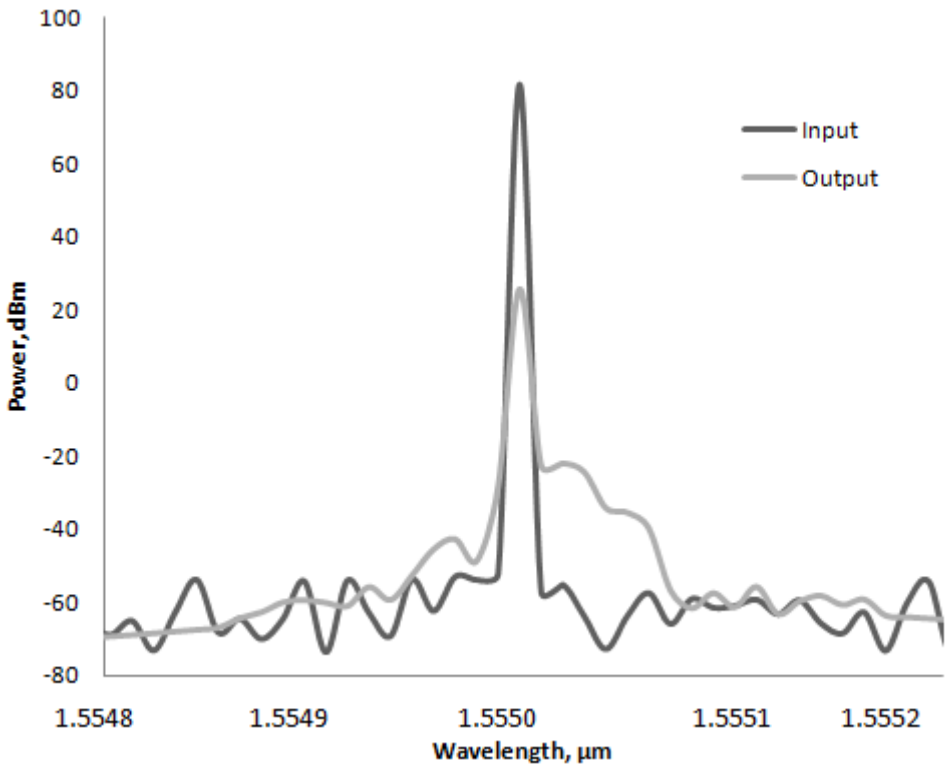

Figure 2: Spectral broadening for 2.5 Gbs^{-1}.

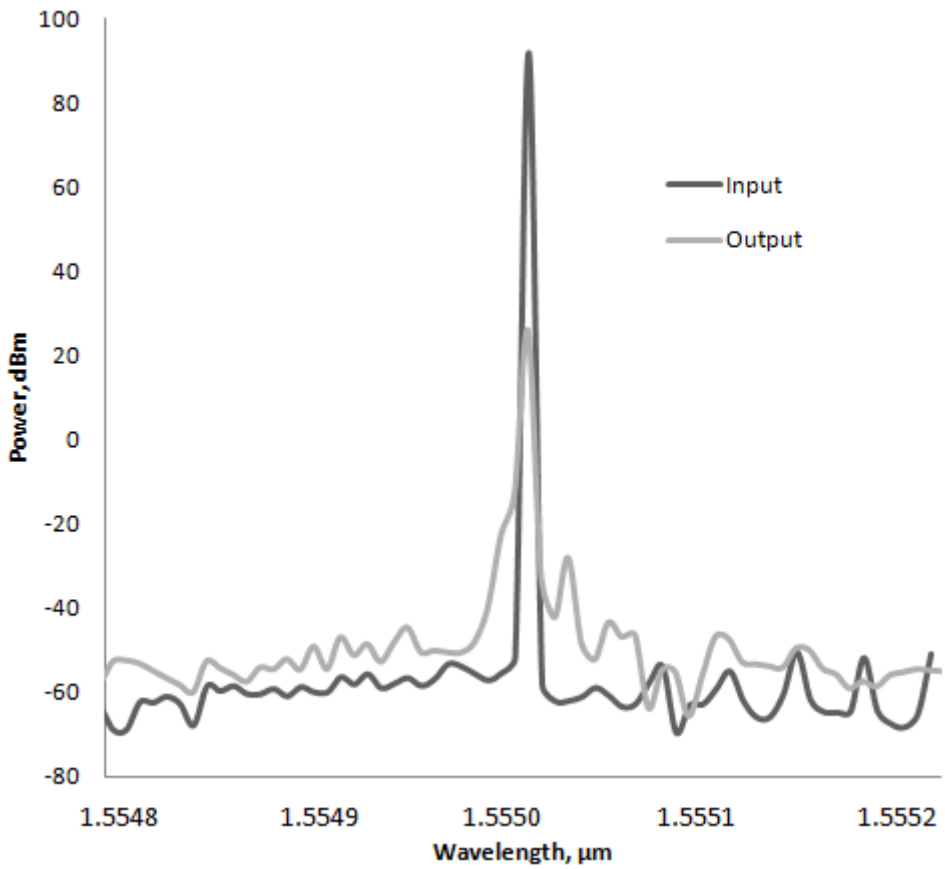

Figure 3: Spectral broadening for 5 Gbs^{-1}.

The spectral broadening for 5 Gbs^{-1} is shown in Figure 3. The figure show the output result broadens than input result. The spectrum broadens 0.08 nm. Figure 4 shows the spectrum of phase modulated for 10 Gbs^{-1}. A comparison between input and output, the spectral broaden 0.06 nm at -40 dBm.

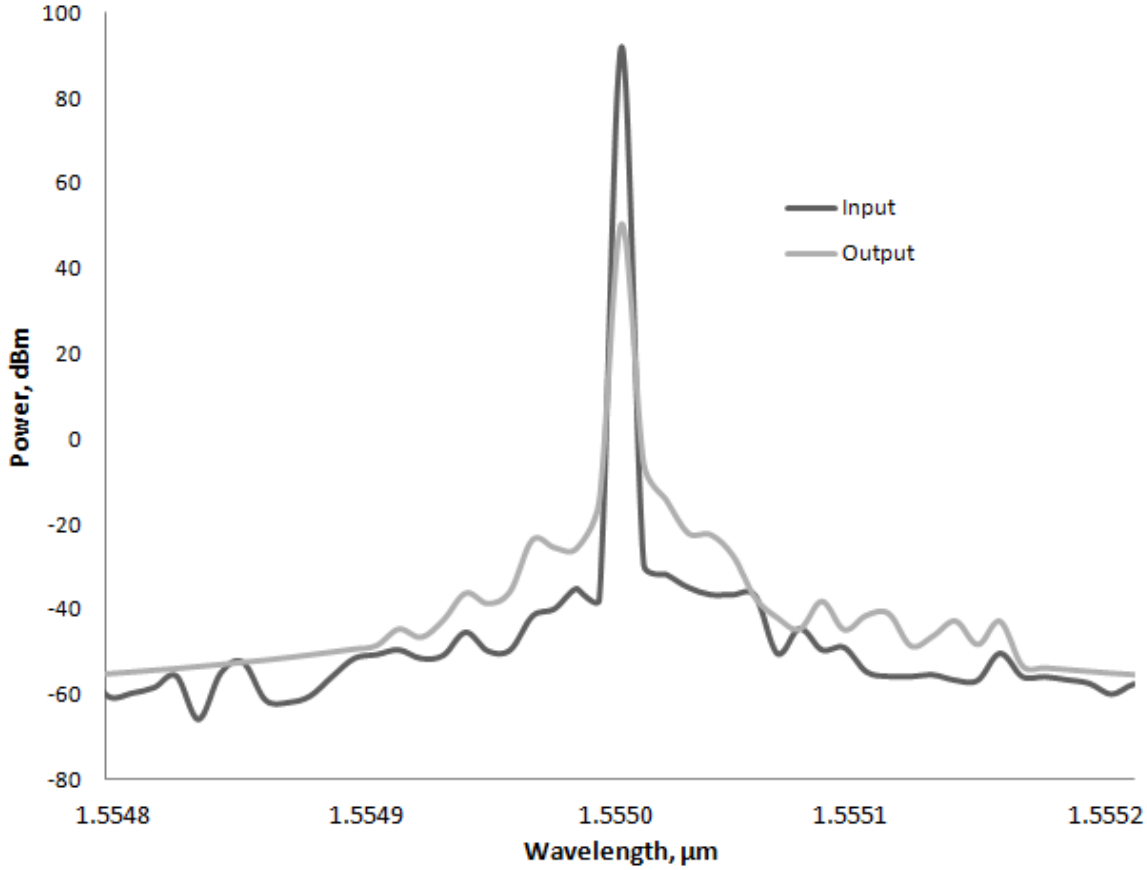

Figure 4: Spectrum of phase modulated for 10 Gbs^{-1}.

Figure 2, Figure 3 and Figure 4 show the results of spectral broadening when different repetition rates applied to the SOA-NOLM. It is clearly observed that the broadening of the spectrum depends on the repetition rate which is depicted in Table 1. This is due to the level of SOA's recovery time. At high repetition rate, the SOA has not fully recovered when the second pulse arrived. Thus, the XPM effect is reduced. As a result, the whole spectrum has a wider broadening. While at a low repetition rate, broadening of the pulses shows an oscillatory structure as given by Equation 5.

Table 1 shows the results with the autocorrelation after spectral filtering at the repetition rates 2.5 Gbs^{-1}, 5 Gbs^{-1} and 10 Gbs^{-1}. This is due to the intensity modulation results by selecting only the phase modulation in the leading and trailing edge of the spectral broadening.

Table 1: The spectrum size with different repetition rate

Repetition Rate, Gbs^{-1}	Spectral Width, m	Power, dBm
2.5	1.80E-10	63.8
5	1.69E-10	62.8
10	1.65E-10	60

3.2 Injection current dependency

In this analysis, the input and the SOA's offset are fixed while SOA's injections currents are varied accordingly from 0.1 A until 0.3 A.

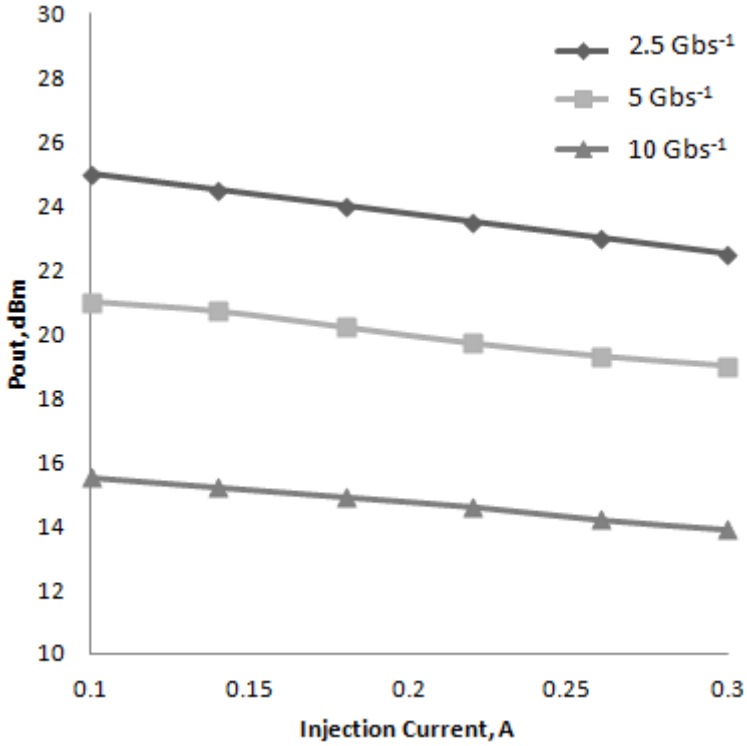

Figure 6: SOA injection current

The SOA injection current dependency is shown in Figure 6. The comparison with three different signals rate shows a low power is needed at higher speed in observing a new oscillation peak. Figure 7 shows the SOA injection current dependency in creation of a peak.

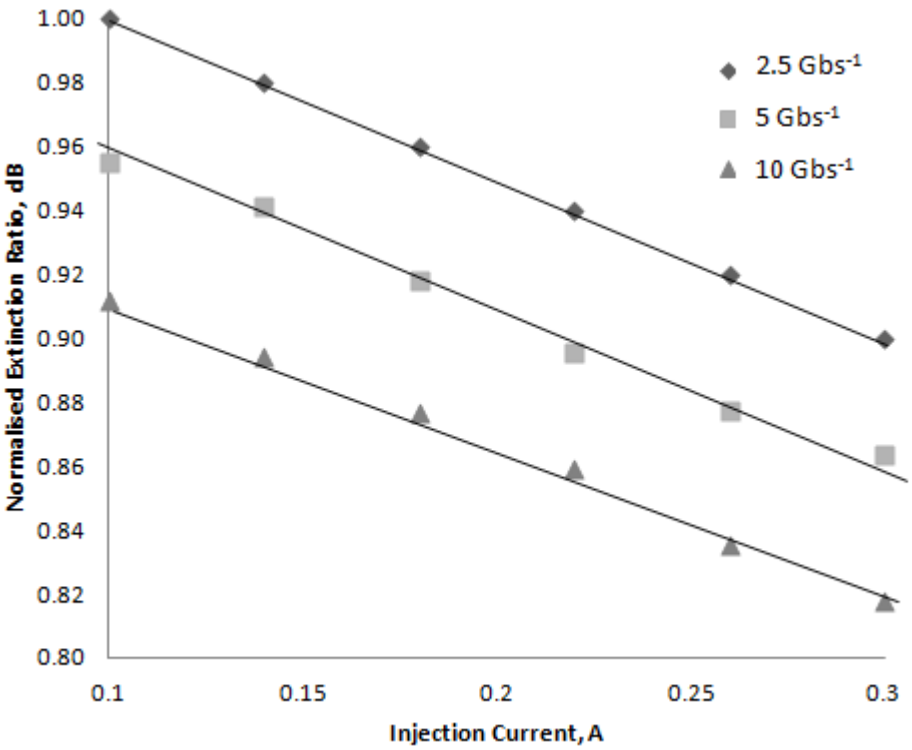

Figure 7: The extinction ratio for SOA's current.

Due to the higher population inversion at large current, the injection of carriers is observed. The XPM induced spectral broadenings accompanied by an oscillatory structure consists of peaks covering the entire frequency range. The number of peaks depends on the phase shift and increases linearly with the injection current. This could be seen from the reduction of extinction ratio as a result of peak creation.

3.3 Switching window dependency

In this simulation, the SOA's injection current is fixed at 0.2 A and the switching window is varied from 100 ps until 200 ps. It is observed that the spectral width has less dependency on the switching window. Figure 8 depicts the observed results. The output power dependency is in the range of ± 2 dBm. This value is very much lower as compared to the actual output power.

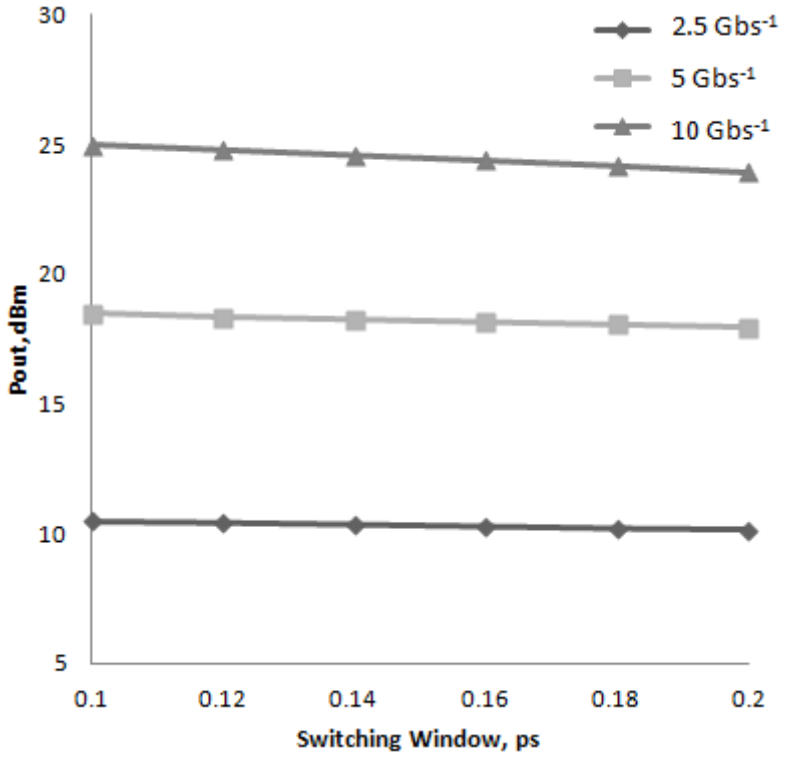

Figure 8: The switching window

However, the extinction ratio of all spectrums at different repetition rate is prominently altered. Figure 9 proves that higher speed produces slower spectral power change.

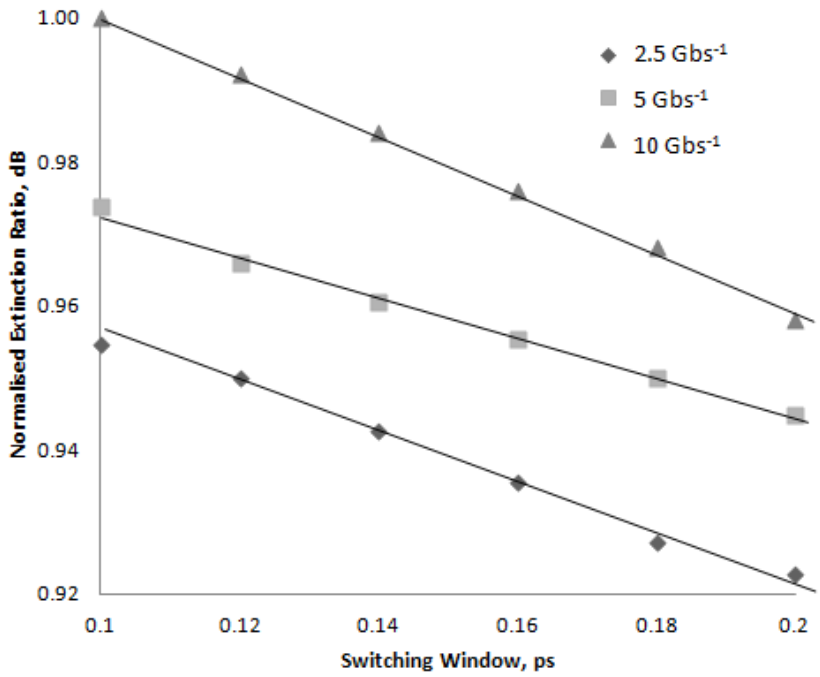

Figure 9: The extinction ratio with the different window size.

4. Conclusion

In this paper, the XPM effect in SOA based NOLM has been observed and explained in details. XPM is the nonlinear phase shift caused by interaction between two or more co-propagating signals, which propagate synchronously along an optical fiber. XPM occurs by interplay between other co-propagating signals through nonlinearities in the SOA and can occur between two optical fields.

The injection current and the offset of the SOA have shown different analysis on pulse broadening in XPM effects. The variation of signal speeds also has an important effect in changing the spectrum. This paper has concentrated on using a simple model to interpret the XPM effect in the SOA based NOLM.

Acknowledgement

The gratefully acknowledgement to FRGS 9003-00234 funding and support this work.

References

Agrawal, G. P. (1997). *Fiber-Optic Communication Systems.* Canada: A Wiley-Interscience Publication.

Agrawal, G. P. (2007). *Nonlinear Fiber Optics.* United State of America: Academic Press.

Downing, J. N. (2005). *Fiber-Optic Communications.* United States of America: Thomson Delmar Learning.

Keiser, G. (2000). *Optical Fiber Communication.* USA: McGraw Hill.

Rogers, A. (2001). *Understanding Optical Fiber Communications.* United State of America: Artech House.