

Simultaneous Wavelength Preserving and Wavelength Converting Regeneration of NRZ DPSK Signal Using FWM in SOA

Anju Thomas¹, Prof.I.Muthumani²

PG Scholar, Department of ECE, A.C College of Engineering and Technology, Karaikudi-630004, India¹

Professor, Department of ECE, A.C College of Engineering and Technology, Karaikudi-630004, India²

Abstract— In this paper, simultaneous wavelength preserving and wavelength converting regeneration of non return-to-zero differential phase-shift-keying (NRZ-DPSK) signals at 10 Gb/s is implemented using the principle of FWM in Semiconductor Optical Amplifier (SOA). Both four-wave-mixing (FWM) and pass-through signals are remarkably improved with respect to input data in terms of Q-factor and bit error rate (BER), demonstrating wavelength preserving and wavelength converting (Both Up and Down conversion) regeneration. In particular, the FWM signal exhibits better regenerative performance over a broader range of degraded input data and for lower input overall power levels.

Index Terms— All-optical regeneration, differential phase shift keying, four-wave-mixing (FWM), semiconductor optical amplifiers (SOAs), wavelength conversion

I. INTRODUCTION

An all-optical regenerator (AOR) improves the quality of an optical signal directly in the optical domain. Therefore, it can replace a power-hungry optoelectronic regenerator. All-optical regeneration was largely investigated in the past, yet mostly for conventional Non Return-to-Zero (NRZ) or Return-to-Zero (RZ) On-Off Keying (OOK) modulation formats. Recently, the research on AOR's also included the application to alternative modulation formats and/or multi-wavelength operation indeed, even a complex AOR would become extremely attractive if it could simultaneously regenerate many signals at different wavelengths, as it could replace in a single shot a number of electronic counterparts. Many methods have been proposed to achieve the regeneration in case of intensity modulation formats,

but failed in the case of phase-modulated signals due to the detrimental nonlinear phase noise.

But, simple and effective methods able to regenerate in the optical domain phase-modulated signals are of great importance for the development of future optical networks. Next-generation coherent systems will indeed use spectrally-efficient advanced and complex modulation formats for better exploitation of channel capacity. Among the others, constant-envelope phase-modulation formats, like Multiple Phase-Shift Keying (M-PSK) and Differential Phase Shift Keying are promising candidates for practical, spectrally-efficient, future long-haul telecom systems.

So simultaneous all-optical regeneration and Wavelength Conversion (WC) of phase-modulated data is a highly regarded feature, as it would enable enhanced network flexibility and robustness in light wave path assignment operation. In this sense, several past works investigated regenerative WC of Differential Phase Shift Keying (DPSK) signals, as this format is a promising candidate for long-haul transmission systems. For instance, some authors proposed DPSK-to-OOK conversion followed by a reshaping nonlinear interferometer stage. These architectures are however suitable only for RZ modulation format; furthermore, either pre-coding or post-detection processing of the converted signal is required in order to retrieve the differential encoding of the original data. Other works concentrated on amplitude regeneration of the converted signal.

This is the 1st scheme which performs regenerative wavelength conversion of NRZ-DPSK signal in a simpler way. In this project it is shown that the phase-preserving amplitude regeneration of DPSK signals by means of FWM in an SOA offers remarkably improved features in presence of NRZ modulation format. Furthermore, it is observed that not only the wavelength-converted signal is regenerated, but also the pass-through data at the original

wavelength exhibit improved features at SOA output, even though with somewhat reduced performances in respect to the FWM signal. Here, the robustness of the regenerative converter against conversion range tuning is investigated. The results show that regenerative operation is achieved in both the down- and up-conversion configurations. Significant Q-factor and BER improvement is observed up to as much as 30 nm of down conversion and 18 nm of up-conversion. In particular, the output Q-factor is more than doubled with respect to the input Q-factor (for an input Q-factor fixed at 15). Experiments are carried out with NRZ-DPSK signals at 10 Gb/s.

II. PRINCIPLE AND EXPERIMENTS

The scheme exploits the amplitude-limiting gain characteristic of a saturated SOA. In particular, the power levels of input signals are properly balanced such that optimal suppression of the amplitude oscillations is attained in concurrence of a nearly suppressed α -factor. As a consequence, very small amplitude-to-phase noise transfer occurs in the amplifier. Under these conditions, after demodulation, the amount of phase noise which is introduced by the SOA can be neglected with respect to the amount of removed amplitude noise and of the input phase noise, enabling effective phase-preserving amplitude regeneration of the DPSK data.

Figure.1 shows the block diagram of the system.

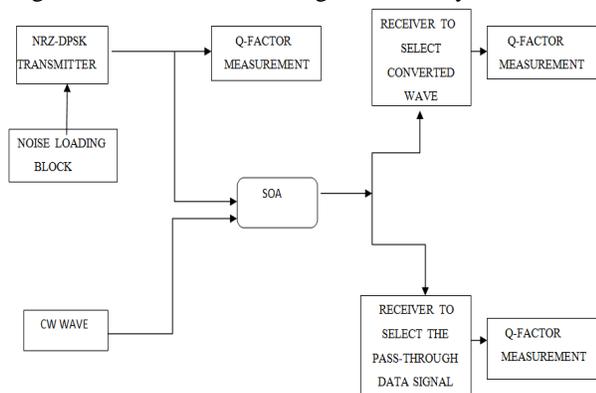


Fig.1 Block diagram of the proposed method.

Main Blocks of the system are given below.

A. Transmitter

A Pseudo Random Bit Sequence generator provides a 10 Gb/s data stream which is given to a precoder and then to a

NRZ-pulse generator to obtain NRZ-DPSK signal in electrical domain. This is given to a LiNb Mach-Zehnder modulator with CW laser at a wavelength λ_{data} as the carrier source. Hence an NRZ-DPSK modulated optical signal at λ_{data} is obtained at the modulator output.

B. Noise Loading Block

In practical optical networks, the data transmitted between the nodes will be noisy. Since, this project demonstrates the regeneration property of the data signal, light from a CW laser at another wavelength is added to make the data signal noise with comparatively low Q-factor. Here the CW laser is followed by an Erbium Doped Fiber Amplifier (EDFA). It acts as a noise source by means of Amplified Spontaneous Emission (ASE). Then it is connected to an optical filter at λ_{data} with 0.1 nm bandwidth.

C. Addition of CW Wave

The basic principle behind this scheme is the Four Wave Mixing in SOA. So another light wave at λ_{CW} is added with the noisy data after sufficient amplification by an EDFA followed by an optical filter at the wavelength λ_{CW} having a bandwidth of 0.3 nm.

D. Amplifier Section

The noisy data is combined with the CW wave using an ideal MUX. It is injected into the Semiconductor Optical Amplifier (SOA). This is a multi-quantum-well device with 30 dB small-signal gain, 13 dBm output saturation power and ~1 dB polarization dependent gain. In the amplifier, nonlinear interaction between the signals produces new wavelengths at the SOA output. From these waves either up converted or down converted wavelength which is a conjugated replica of the data signal at λ_{FWM} are selected by a tunable OF with 0.3 nm bandwidth.

Converted wave either at $\lambda_{FWM}=1548$ nm for down conversion case and $\lambda_{FWM}=1557$ nm for up conversion, with better regeneration is obtained at the SOA output. The signal at the converted wavelength can be viewed in the Optical Spectrum analyser.

In the amplifier, nonlinear interaction between the signals produces a FWM term at

$$\lambda_{FWM} = (2/\lambda_{CW} - 1/\lambda_{data})^{-1} \quad (1)$$

which is a conjugated replica of the data signal.

By proper balancing of the input signals' power allows us to exploit the amplitude limiting effect of SOA saturated gain without introducing significant excess phase noise

other than the additional phase noise introduced due to the DPSK modulation by the suppression of the α -factor in the amplifier.

At the SOA output, the converted data at λ_{FWM} are selected by a tunable OF with 0.8 nm bandwidth. The FWM light is subsequently raised by a second EDFA, followed by an OF with 0.3 nm bandwidth to eliminate the out-band ASE from the fiber amplifier. Q-factor of the input/output signals is measured. In measuring the input Q-factor, input data is directly connected to the same 0.3 nm OF centered at λ_{data} . We then performed a broadband characterization of the regenerative WC under different conditions of data-pump detuning. By adjusting the central frequency of the TMs used to generate the input data and the CW pump, the wavelength of FWM light is kept fixed at either $\lambda_{\text{FWM-DC}} = 1548$ nm (wavelength down-conversion case) or at $\lambda_{\text{FWM-UC}} = 1557$ nm (wavelength up-conversion case), for all the considered values of the wavelength conversion span,

$$\Delta \lambda = (\lambda_{\text{FWM}} - \lambda_{\text{data}}). \quad (2)$$

E. Receiver Block

First block at the receiver section is the one-bit-delay Mach-Zehnder Interferometer (MZI) which is used as the DPSK optical receiver. MZI is used to correlate each bit with its neighbor and make the phase-to-intensity conversion. It is realized by tunable delay unit and phase shift in two arms of two X-coupler connected together. They convert a phase-keyed signal into an amplitude-keyed signal. In this application, an incoming differential phase-shift keying (DPSK) optical signal is first split into two equal-intensity beams in two arms of a Mach Zehnder or Michelson interferometer, in which one beam is delayed by an optical path difference corresponding to 1-bit time delay. There are two outputs of MZI, called constructive port or destructive port respectively. For constructive port, when the two consecutive bits are in-phase, they are added constructively in the MZI and results in a high signal level; otherwise, if there is a π phase difference between the two bits, they cancel each other in the MZI and results in a low signal level. For destructive port, it is vice-versa. The two output arms of the MZI are given to separate Photo detectors. Each detector will give corresponding electrical signals at the output. Then second electrical signal is subtracted from the first by using an Electrical Subtractor. Hence electrical NRZ- DPSK signal is obtained at the subtractor output. It is suitably filtered by a low-pass Bessel Filter to get a better output signal. The Filter output is connected to a 3R regenerator. This component regenerates

an electrical signal. It generates the original bit sequence, and a modulated electrical signal to be used for BER analysis. It is a subsystem based on the Data Recovery component and a NRZ Pulse Generator. The three output signals namely binary data sequence, reference and output electrical signals are given to the BER analyzer. Improved Q-factor and BER of the converted signal can be measured in the BER analyzer.

F. Simultaneous Regeneration Of Pass-Through Data And Converted Wave

It is observed that not only the wavelength-converted signal is regenerated, but also the pass-through data at the original wavelength also exhibit improved features at SOA output, even though with somewhat reduced performances in respect to the FWM signal. But the pass-through data shows a remarkable enhancement in the Q-factor by increasing data power well above the CW power.

So the same receiver section implemented to measure the Q-factor of the wavelength converted signal is used. The change is that SOA output is we connected also to another 0.3 nm OF centered at λ_{data} . In measuring the input Q-factor, input data is directly connected to the same 0.3 nm OF centered at λ_{data} .

III. RESULTS AND DISCUSSION

For the existing system the obtained eyediagrams at the input and output with the corresponding power levels of the data and cw wave is given in the following section.

In this characterization, the Q-factor of the input data is kept fixed at $Q_{\text{IN}} = 15$ for the easy analysis of the variation of Q-factor with respect to the change in the wavelength.

A. Regeneration Of Converted Data Alone

1) Input data signal with a fixed value of $Q_{\text{IN}} = 15$

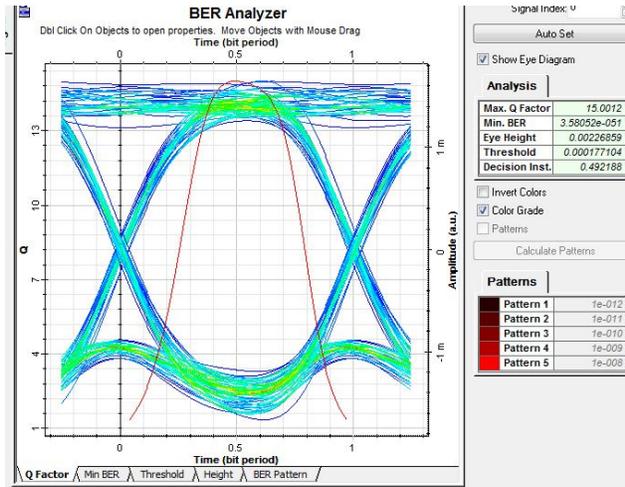


Fig 2. Eye diagram of the input signal with Q =15

Output is observed for the down converted and up converted waves with wavelength conversion span, $\Delta \lambda$

2) Down conversion

Wavelength of the Converted wave =1548nm

(i) $\Delta \lambda = -6\text{nm}$

$\lambda_{\text{data}} = 1554 \text{ nm}$

$P_{\text{data}} = 3 \text{ dBm}$

$\lambda_{\text{cw}} = 1551 \text{ nm}$

$P_{\text{cw}} = 7.5 \text{ dBm}$

$Q_{\text{fwm out}} = 37.5632$
309

$\text{BER} = 4.23749\text{e-}309$

(ii) $\Delta \lambda = -12\text{nm}$

$\lambda_{\text{data}} = 1560 \text{ nm}$

$P_{\text{data}} = 4.2\text{dBm}$

$\lambda_{\text{cw}} = 1554 \text{ nm}$

$P_{\text{cw}} = 11.5 \text{ dBm}$

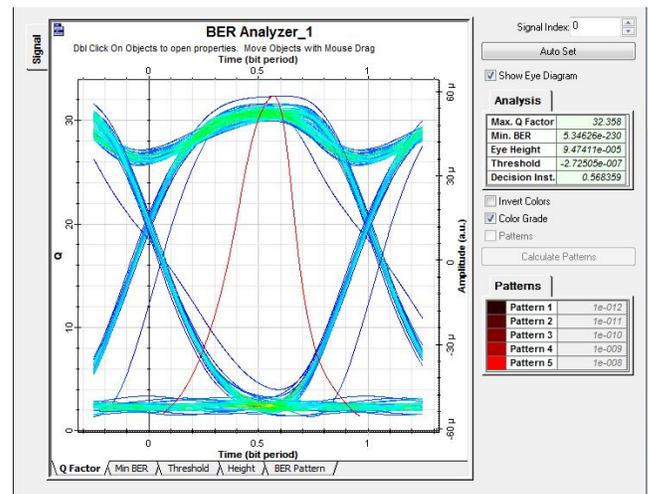


Fig 4. Eye diagram of the output converted signal for $\Delta \lambda = -12\text{nm}$

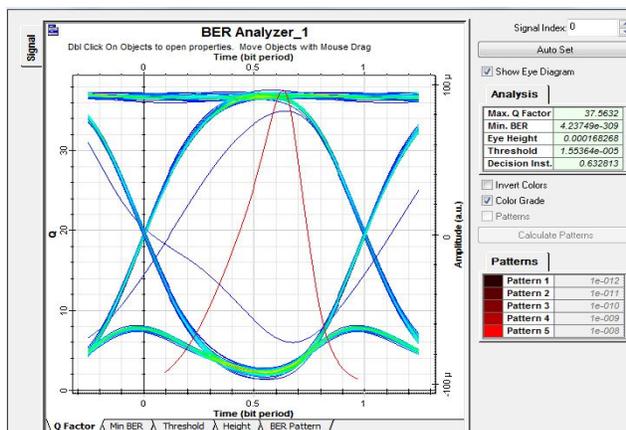


Fig 3. Eye diagram of the output converted signal for $\Delta \lambda = -6\text{nm}$

$Q_{\text{fwm out}} = 32.358$
230

$\text{BER} = 5.34626\text{e-}230$

(iii) $\Delta \lambda = -18\text{nm}$

$\lambda_{\text{data}} = 1566 \text{ nm}$

$P_{\text{data}} = 6.2\text{dBm}$

$\lambda_{\text{cw}} = 1557 \text{ nm}$

$P_{\text{cw}} = 13.98 \text{ dBm}$

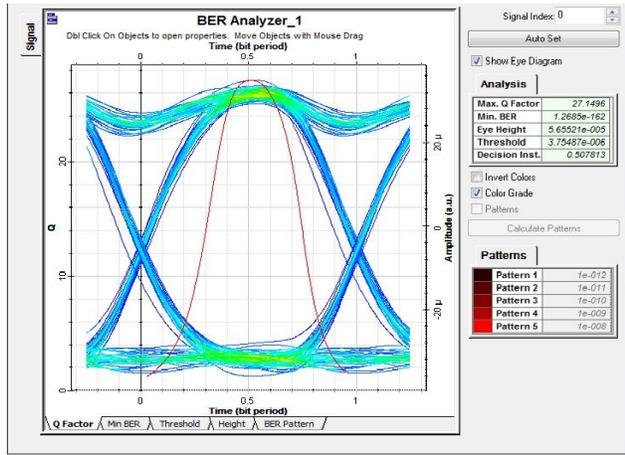


Fig 5. Eye diagram of the output converted signal for $\Delta\lambda = -18\text{nm}$

$Q_{\text{fwm out}} = 27.1496$ $\text{BER} = 1.2685\text{e-}162$

3) Up conversion

Wavelength of the Converted wave = 1557nm

(i) $\Delta\lambda = 6\text{nm}$

$\lambda_{\text{data}} = 1551\text{nm}$ $P_{\text{data}} = 8.8\text{ dBm}$

$\lambda_{\text{cw}} = 1554\text{nm}$ $P_{\text{cw}} = 10.3\text{ dBm}$

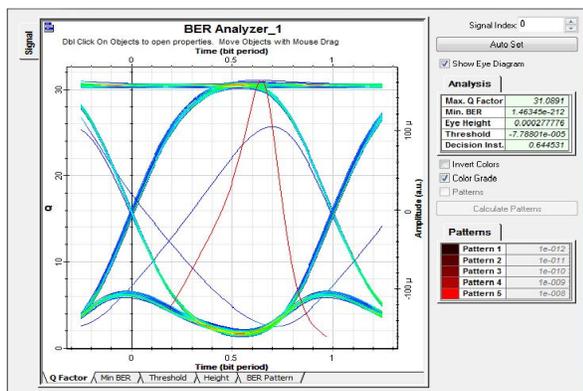


Fig 6. Eye diagram of the converted output signal for $\Delta\lambda = 6\text{nm}$

$Q_{\text{fwm out}} = 31.0891$ $\text{BER} = 1.46345\text{e-}212$

(ii) $\Delta\lambda = 12\text{nm}$

$\lambda_{\text{data}} = 1545\text{nm}$ $P_{\text{data}} = 10.3\text{ dBm}$

$\lambda_{\text{cw}} = 1551\text{nm}$ $P_{\text{cw}} = 11.09\text{ dBm}$

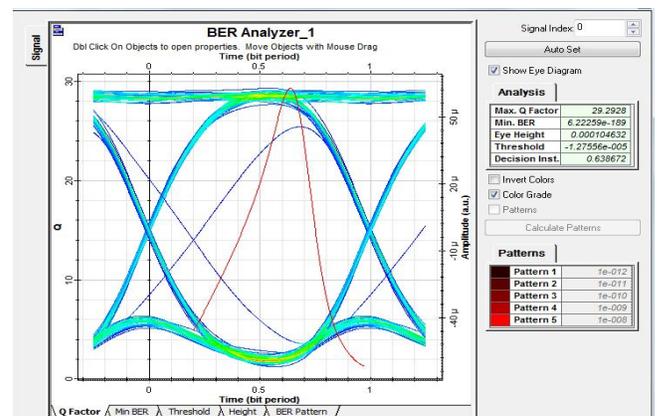


Fig 7. Eye diagram of the converted output signal for $\Delta\lambda = 12\text{nm}$

$Q_{\text{fwm out}} = 29.2928$ $\text{BER} = 6.22259\text{e-}189$

(iii) $\Delta\lambda = 18\text{nm}$

$\lambda_{\text{data}} = 1539\text{nm}$ $P_{\text{data}} = 7.558\text{ dBm}$

$\lambda_{\text{cw}} = 1548\text{nm}$ $P_{\text{cw}} = 7.708\text{ dBm}$

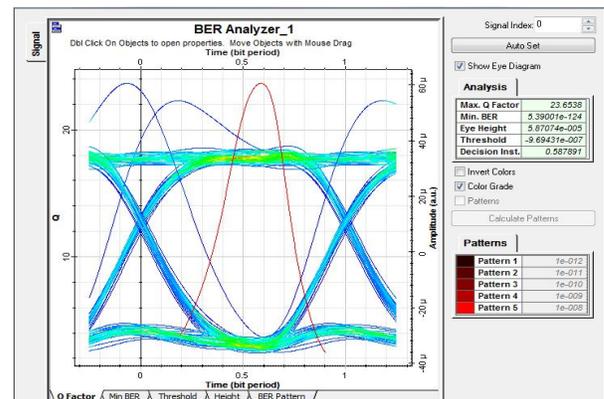


Fig 8. Eye diagram of the converted output signal for $\Delta\lambda = 18 \text{ nm}$

$$Q_{\text{fwm out}} = 23.6538 \quad \text{BER} = 5.390001e-124$$

The obtained values of Q-factor and BER of the converted data corresponding to the increase in wavelength span for both Down conversion and Up conversion is tabulated below.

TABLE I
COMPARATIVE TABLE OF RESULTS OBTAINED FROM THE SIMULATION VARIATION OF Q-FACTOR AND BER OF THE CONVERTED DATA WITH WAVELENGTH SPAN

$\Delta\lambda$	Down conversion				Up conversion			
	λ_{data} nm	λ_{cw} nm	Q_{fwm}	BER	λ_{data} nm	λ_{cw} nm	Q_{fwm}	BER
6 Nm	1554	1551	37.5632	4.23749e-309	1551	1554	31.0891	1.46345e-212
12 Nm	1560	1554	32.358	5.34626e-230	1545	1551	29.2928	6.22259e-189
18 Nm	1566	1551	27.1496	1.2685e-162	1539	1548	23.6538	5.39e-124

Fig 9. Eye diagram of the input signal with $Q = 7$

$$\Delta\lambda = -6 \text{ nm}$$

$$\lambda_{\text{data}} = 1554 \text{ nm}$$

$$P_{\text{data}} = 2.5 \text{ dBm}$$

$$\lambda_{\text{cw}} = 1551 \text{ nm}$$

$$P_{\text{cw}} = 1 \text{ dBm}$$

2) Converted output signal

Here, the robustness of the regenerative converter against conversion range tuning is investigated. The results show that regenerative operation is achieved in both the down- and up-conversion configurations. By keeping fixed the Q-factor of input data, we observed enhanced features of the output converted data over a broad conversion range for the wavelength down- and up-conversion configurations, respectively.

The different behaviour for the wavelength down- and up-conversion cases is clearly due to the lower conversion efficiency in wavelength up-conversion with respect to down-conversion, because of the different phase contribution of the various physical effects in FWM process. Also, the wavelength down-converted signal benefits from ASE tilting in the saturated semiconductor amplifier.

B. Simultaneous Regeneration converted and pass-through data

1) Input data signal with a fixed value of $Q_{\text{IN}} = 7$

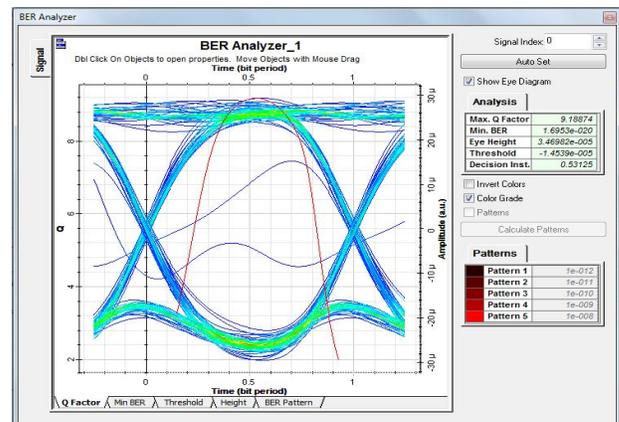
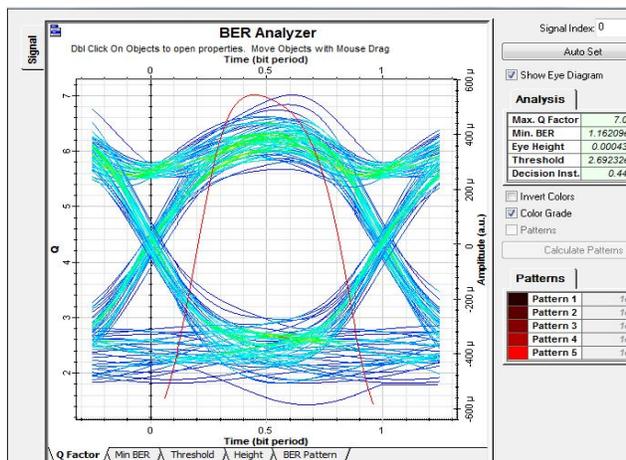


Fig 10. Eye diagram of the converted output signal for $\Delta\lambda = -6 \text{ nm}$

$$Q_{\text{fwm out}} = 9.18874$$

$$\text{BER} = 1.6953e-020$$

International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization,

Volume 3, Special Issue 1, February 2014

International Conference on Engineering Technology and Science-(ICETS'14) On 10th & 11th February Organized by

Department of CIVIL, CSE, ECE, EEE, MECHANICAL Engg. and S&H of Muthayammal College of Engineering, Rasipuram, Tamilnadu, India

- [9]. Wang, A. Maitra, C. G. Poulton, W. Freude, and J. Leuthold, "Temporal dynamics of the alpha factor in semiconductor optical amplifiers," *J. Lightw. Technol.*, vol. 25, no. 3, pp. 891–900, Mar. 2007.
- [10]. G. Contestabile, M. Presi, and E. Ciaramella, "All-optical regeneration of 40 Gb/s constant envelope alternative modulation formats," *IEEE J. Quantum Electron.*, vol. 46, no. 3, pp. 340–346, Mar. 2010.
- [11]. G. Guekos, *Photonic Devices for Telecommunications*. Berlin, Germany:Springer-Verlag, 1999.
- [12]. C. Porzi, A. Bogoni, L. Poti, and G. Contestabile, "Polarization and wavelength-independent time-division demultiplexing based on copolarized-pumps FWM in an SOA," *IEEE Photon. Technol. Lett.*, vol. 17, no. 3, pp. 633–635, Mar.
- [13]. Tomofumi Kise, Kimchau N. Nguyen, John M. Garcia, Henrik N. Poulsen, and Daniel J. Blumenthal, "Demonstration of Cascadability and Phase Regeneration of SOA-Based All-Optical DPSK Wavelength Converters", May,2011