An All-optical 3R Regenerator Using Fiber-based Four Wave Mixing

Theint Theint Htike, Zaw Myo lwin, Hla Myo Tun

Abstract: All optical 3R regeneration is a key function of the future all optical network and ultra-long-haul transmission. In this paper, all-optical regenerator utilizes a Fabry-Perot (F-P) filter for clock recovery, four wavemixing based in a 500m-long highly nonlinear fiber and optical band pass filter for retiming and reshaping. A 10Gb/s RZ signal was transmitted through 1200 km with a power penalty of 1dB at a BER of 10^{-9} compared to the back-to-back case. All optical 3R is shown to improve the performance of input signals degraded by transmission impairments and timing jitter of 10ps is reduced.

Index Terms: All-optical regeneration, four wave mixing (FWM), highly nonlinear fiber (HNLF), optical band pass filter

I. INTRODUCTION

In long-haul optical transmission systems, the group velocity dispersion, polarisation mode dispersion, the non-linearity of the fibre, crosstalk and noise accumulation, which lead to pulse broadening, timing jitter and waveform distortion. All-optical 3R regeneration (Reamplification, Retiming, and Reshaping) in the transmission system is an effective method to overcome these problems [1]. An all-optical 3R regenerator adds a retiming function to reduce the timing jitter of 10ps by recovering an optical clock signal from data signal. Many techniques have been reported for all-optical clock recovery and 3R regeneration. Among these techniques, Fabry-Perot(F-P) filter for clock recovery[2] and the retiming function of a regenerator can be achieved by using cross phase modulation effect in highly nonlinear fiber and optical band pass filter[3]. The technology for clock recovery is direct filtering out the frequency components of the clock signal with Fabry-Perot (F-P)filter. In this paper, the retiming technique is combined with a 2R regenerator based on FWM in an HNLF and optical band pass filter to achieve 3R regeneration for a bit rate of 10 Gb/s. The regenerator performance is characterized in terms of the timing jitter, power attenuation, waveform distortion, receiver sensitivity and BER curve. This paper is organized as follows; section II describes principle of 3R regeneration by FWM and optical band pass filter. Section III explainssimulation setup. In section IV, simulation result is described and finally the paper is concluded in section V.

I. PRINCIPLE OF 3R REGENERATION BY USING FOUR WAVE MIXING

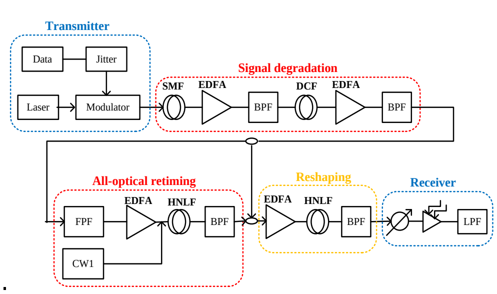


Fig.1. *Block diagram of the proposed design work*

The operation principle of the all-optical 3R regenerator is illustrated in fig [1]. It includes signal transmission, signal degradation, an all-optical retiming, 2R stage and receiver. In signal transmission, transmitter transmits the data signal (including jitter) is passed through the signal degradation. In the signal degradation, dispersion compensation fibre operates dispersion compensation after single mode fibre [4]. An optical amplifier operates to recover the fibre loss and optical band pass filter is used to reject the ASE noise caused by EDFA after each types of fibre length. Then the signal becomes attenuation, timing jitter and waveform distortion. Each transmission span consists of 100km long single mode fibre and 20km long dispersion compensation fibre and the signal is degraded by 10 transmission spans. And then the signal is split into two paths. One path is applied to the Fabry-Perot (F-P) filter to extract a clock signal.In a clock recovery path, the 10 Gb/s all optical clock recovery module is built with a Fabry-Perot (F-P) filter. The principle of the clock recovery by the Fabry-Perot (F-P) filtercan be analysed from the frequency domain and the time domain, respectively. The free spectral range (FSR) of the F-P filter is

$$FSR = \frac{c}{2nL}$$

(1)Where c is the velocity of light in vacuum, n is the refractive index which is approximately 1 and the cavity length L is 0.015m. The Fabry-Perot(F-P) filter has a free spectral range (FSR) of 10GHz and a finesse of 1000. The finesse F is defined as the ratio of the FSR to its path bandwidth Δf, which is the optical frequency full width at half maximum of any intensity resonance peak. The bandwidth of the Fabry-Perot (F-P) filter is

$$\Delta f = \frac{FSR}{F} = 0.01GHz \qquad (2)$$

The signal measured directly after the Fabry-Perot (F-P) filter with10Gb/s Gaussian input signals with 2^7-1 PRBS [5]. The extinction ratio of the clock extracted from Fabry-Perot (F-P) filter is lower.And the clock signal power is amplified by erbium doped fibre (EDFA). As the need of FWM, there are required two different wavelengths. So wavelength conversion is necessary for the retiming stage. In the wave length conversion stage, the amplified clock signal is combined with a wavelength tunable CW wave pump laser using a coupler. The combined signal is launched into a HNLF to produce FWM effect. The FWM effect in HNLF can be generally described as follows; P_1 (Pump) and P_2(signal) are the input optical power values for two continuous waves at frequencies

ω_1, ω_2, are injected into a HNLF with 0.5km length through FWM process. The creation of new product waves, the conjugate and satellite at optical frequencies (ω_3 and ω_4) respectively with $\omega_3=2\omega_1-\omega_2$ and $\omega_4=2\omega_2-\omega_1$ will be generated with power P_4 (conjugate wave) and p_3 (satellite wave) as shown in fig.2 [6].The two linear coupled equations for the signal and idler fields is

$$\frac{dA_{signal}}{d_z} = -2i\gamma[2PA_3 + Pe^{-i\theta}A_4^*] \qquad (3)$$

$$\frac{dA_{idler}}{d_z} = -2i\gamma\ [2PA_4^* + Pe^{i\theta}A_3] \qquad (4)$$

Where $A_{signal}$is the input signal of the 500m- long HNLF and $A_{idler}$is the idler of the converted wavelength, γ is the nonlinearity coefficient , A_4^* is the conjugate of the pump wave and A_3 is the satellite wave.

Where; $\theta = [\Delta k - 6\gamma P]z$

z is the propagation distance along the fibre[7]. Optical band pass filter is placed at the output of the HNLF and selects the conjugate wave at 1549nm. Because the extinction ratio of the conjugate wave is better than the other wave. In a retiming stage, FWM scheme has been considered where a strong CW pump and a weaker modulated signal are launched into the HNLF. Based on the earlier assumption, mosttheoretical models, have taken into account only the stronger of the two generated output first order products (conjugate) and neglect the weaker one (satellite). At the output of the HNLF all optical retimed signal can be obtained by selecting the conjugate wave. In the reshaping stage, coupler combines the degraded signal and retimed signal. These signal are reamplified, reshaped and wavelength conversion using FWM in a HNLF. Optical band pass filter is placed at the output of the HNLF and selects the conjugate wave. This produces the 3R regenerated output signal. A variable optical attenuator, a lowpass Bessel filter and a photodiode are used as the receiver.

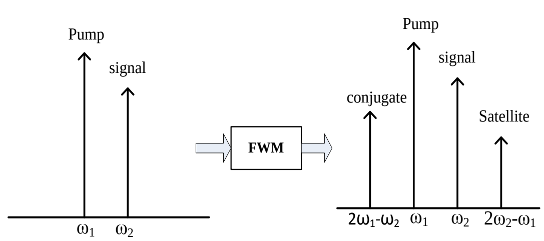


Figure2. *Principal of operation of FWM in HNLF*

Simulation setup of the 3R regenerator by using Optisystem software is illustrated in fig.2.The CW laser and 10Gb/s RZ pseudo random bit sequence signal including 0.3UI jitter amplitude is modulated by Mach-Zehnder Modulator and then is sent to the signal degradation. In the signal degradation dispersion compensation is done by DCF with a dispersion of -80ps/nm/km, a dispersion slope of -0.5ps/nm^2/km, a nonlinear coefficient of 5.2Wkm^{-1}, a length of 20km after 100km long single mode fiber with a dispersion of 10ps/nm/km, a dispersion slope of 0.08ps/nm^2/km, a nonlinear coefficient of 1.3W^{-1}km$^{-1,}$ and attenuation of 0.2dB/km. To recover the fibre loss, EDFA with 20dB gain and 12dB gain are used and OBPF is used to reject the ASE noise caused by EDFA. A 10Gb/s RZ signal was degraded 10 times in order to prove its performance. After signal degradation, the degraded signal is split into two paths. One path is applied to the retiming stage and another path is for reshaping. In the retiming stage, an optical clock signal is recovered through Fabry-Perot(F-P) filter (FSR=10GHz and whose full width half maximum FWHM is only 0.01GHz). The clock signal is amplified by EDFA with 30dB gain. The amplified clock signal is combined with a continuous wave using a 0dB coupler. The combined signal is launched into a 0.5km long HNLF as a nonlinear medium for the four wave mixing. The HNLF used in a proposed system has a dispersion of –0.08ps/km/nm at 1552nm with a dispersion slope of 0.032ps/nm/km and the attenuation of the fibre 0.47dB/km. An optical bandpass filter with bandwidth of 0.15nm is used to filter out the converted signal at 1549nm and then wavelength conversion and retimed data signal is obtained.In the reshaping stage, 0dB coupler combines the retimed signal and degraded signal. Then EDFA amplifies the combined signal and then launched into the 0.5km long HNLF which has the same property.Optical band pass filter select the conjugate wave at 1548nm with 0.15nm and this produce the regenerative output signal. With the similar process, the output signal achieves power penalty of 1dB after transmission. At the receiver BER measurement are carried out to see the performance of the regenerator.

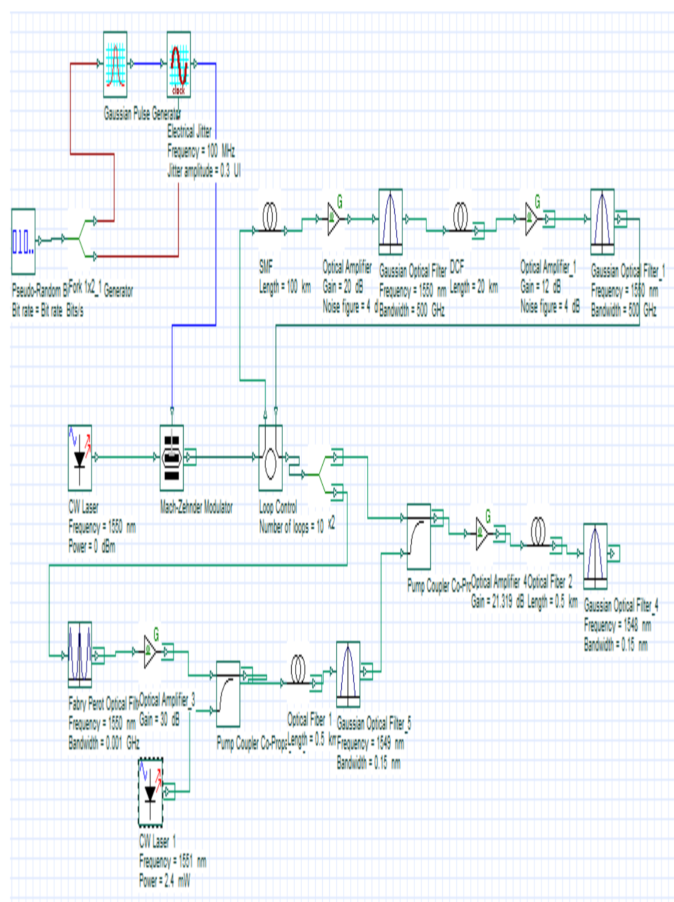


Figure 3. *Simulation Setup of the Proposed System*

II. SIMULATION RESULTS

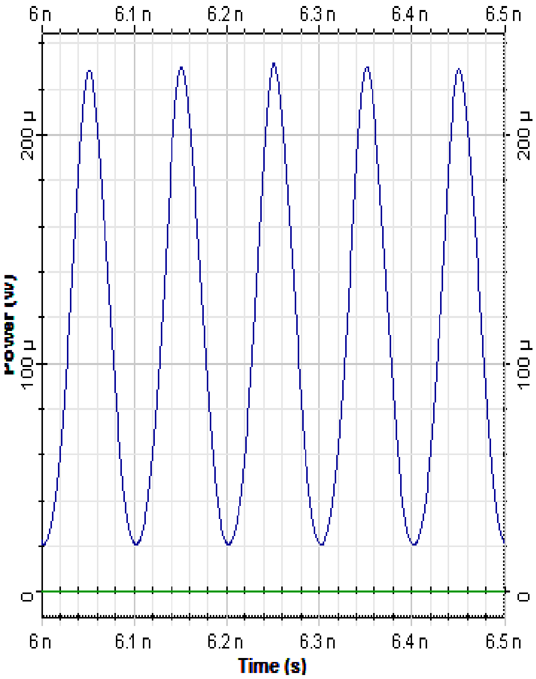
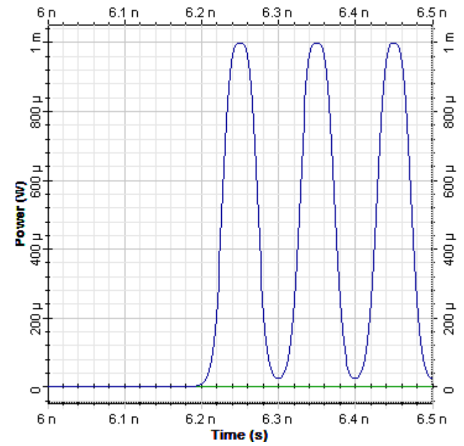


Figure.4. *Extracted clock from Fabry Perot (F-P) filter*

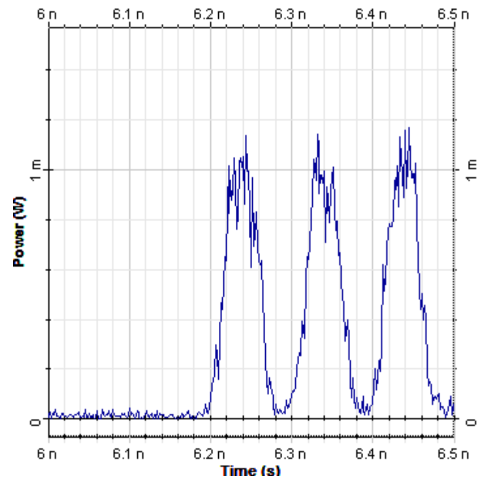
Fig.4. shows the clock extracted from the high-finesse Fabry-Perot(F-P) filter and 10ps timing jitter of degraded signal is reduced.Simulation parameters for the 3R regenerator are shown in table.1

Table 1. *Simulation parameters for 3R regenerator*

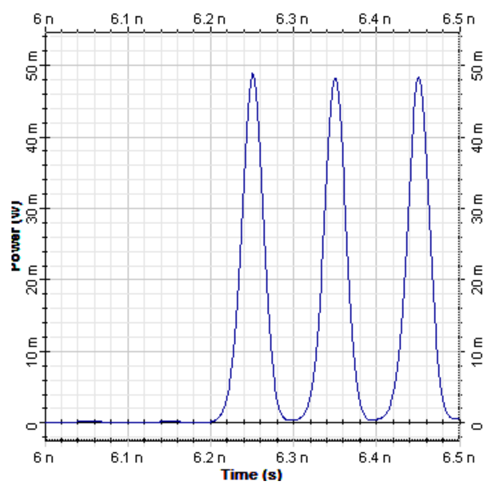
Pump	Wavelength	1550nm
	Laser Power	0dBm
CW	Wavelength	1551nm
	Laser Power	3.8dBm
EDFA1	Gain	30dB
BPF1	Bandwidth	0.15nm
HNLF	Lengths	0.5km
	Attenuation	0.47dB/km
	Dispersion	-0.08ps/nm/km
EDFA2	Gain	21.319dB
BPF2	Bandwidth	0.15nm



(a)



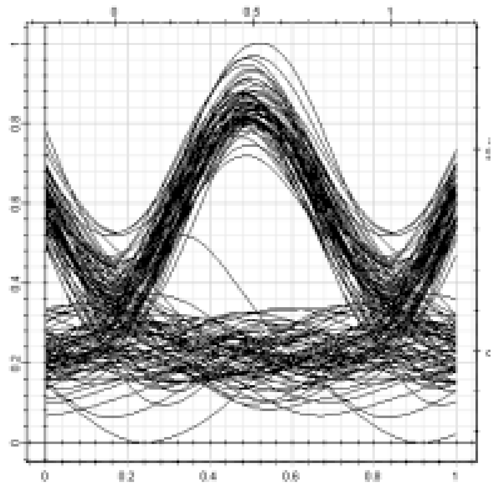
(b)



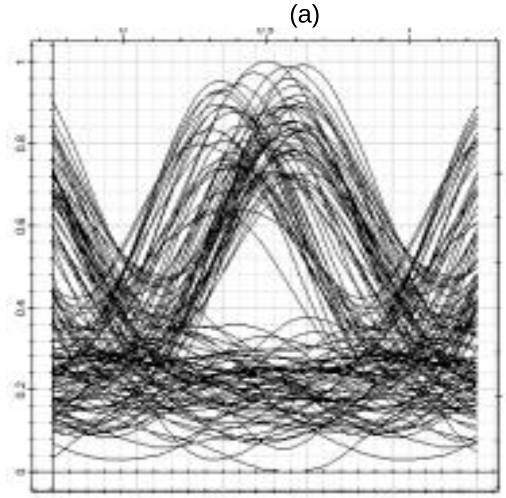
(c)

Fig.5. *Waveforms for (a) Transmitted signal (b) Degraded signal (after 1200 km), and (c) Regenerated signal*

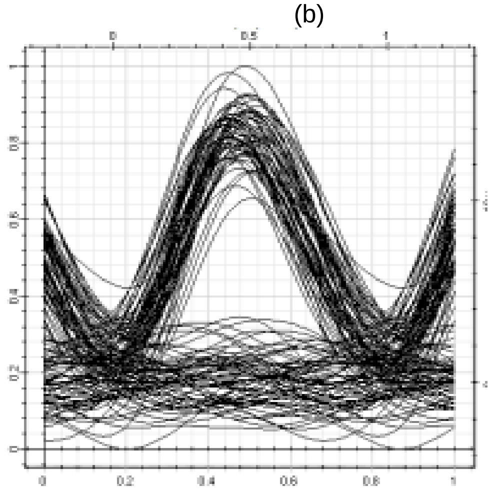
Fig.5 (a) is an input signal waveform of 10Gb/s RZ signal and Fig.5 (b) is the degraded signal after 1200km transmission fibre. Fig.5 (c) shows the output signal after 3R regeneration. The regenerated output waveforms are nearly the same as the input waveforms and timing jitter of 10ps can be reduced



(a)



(b)



(c)

Fig.6.*Eye diagrams for (a) back-to-back system, (b) without regenerator after passing through 1200km transmission fibre, and (c) after regeneration at approximately 10^{-9} BER*

Eye diagram of the original input signal, degraded signal and regenerated signal are compared in Fig.6. As seen in fig.6. More eye opening is observed in the regenerated signal than the degraded signal. And the regenerated eye diagram has higher than the degraded signal.

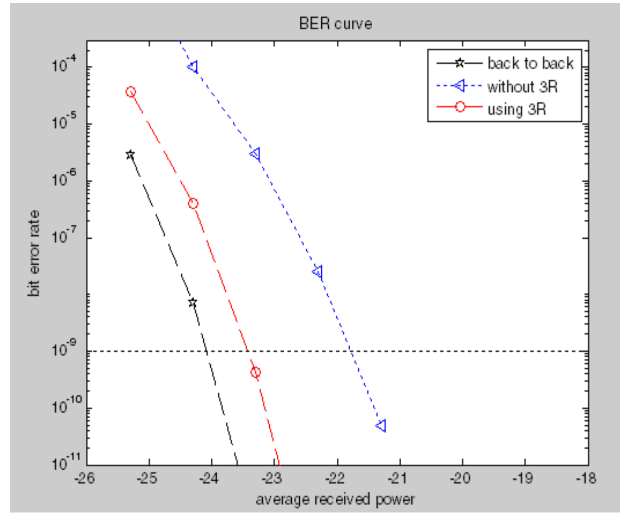


Fig.7. *BER measurement for 3R regenerator*

Fig.7. depicts the bit error rate (BER) characteristics for 3R regenerator. From this figure the receiver-power penalties (dB) relative to the back-to-back measurement at a BER of $10^{-9}$are 1dB for 3R regenerator. And the result shows that the BER performance of the 3R is better than the one without 3R.

III. Conclusion

An all-optical 3R regenerator has been demonstrated for 10Gb/s RZ signal with pulse widths of 33 ps. A Fabry Perot (F-P) filter has been used for the all-optical clock recovery, FWM in HNLF and optical band pass filter for retiming and reshaping. The proposed regenerator can suppress amplitude noise in the one and zero levels with low timing jitter and reshape the distorted signal into original input signal. A10 Gb/s signal was transmitted over 1200 km with a power penalty of 1 dB compared to the back-to-back case at a BER of 10^{-9}. This 3R regenerator can regenerate the degraded signal (with 10ps jitter) which has passed through 1200km long transmission fiber.

Acknowledgment

The author acknowledge to her supervisor for his helpful suggestions and invaluable guidance. The author also would like to thank all her teachers at Mandalay Technological University for their constructive advice throughout the preparation of this research. In particular, I would like to thank my parents.

References

[1] All optical 3R regeneration based on the cross phase modulation effect of semiconductor optical amplifier. Jinlong Yu,1,2 Hao Hu,1,2 Aixu Zhang,1,2 Yaotian Wang,1,2 Likai Zhu,1,2 Wenrui Wang,1,2 Litai Zhang,1,2 Wencai Jing,3 Dagong Jia,3 and Enze Yang1,2

[2] A simple method for clock recoveryTong Wang∗, Caiyun Lou, Li Huo, Zhaoxin Wang, YizhiGaoDepartment of Electronic Engineering, Tsinghua University, Beijing 100084, PR ChinaReceived 11 June 2003; received in revised form 24 December 2003; accepted 5 January 2004

[3] ALL-OPTICAL 3R REGENERATIONBASED ON THE XPM EFFECT OF SEMICONDUCTOR OPTICAL AMPLIFIER Jinlong Yu,1,2 Hao Hu,1,2 Aixu Zhang,1,2 Yaotian Wang,1,2 Likai Zhu,1,2 Wenrui Wang,1,2 Litai Zhang,1,2 Wencai Jing,3 Dagong Jia,3 and Enze Yang1,2

[4] SoeSoeHnaung, “Design and Implementation of 10Gbps All- Optical 2R Regenerator” International Journal of Computational Engineering and Manage - ment (IJCEM), Volume. 17 Issues 3 May 2012

[5] Optical Tank Circuits Used for All-Optical TimingRecovery Masahiko Jinno, *Member, IEEE* and Takao Matsumoto, *Member, IEEE*

[6] Investigation of a 2R All-Optical Regenerator Based on Four-Wave Mixing in a Semiconductor Optical Amplifier

[7] H.Simos, A. Bogris, and D. Syvridis

[8] Nonlinear Fiber Optics " Govind P. Agrawal'. University of Rochester