Design and Implementation of 10Gbps All-Optical 2R Regenerator

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Abstract

An All-optical 2R regenerator (Reamplification and Reshaping) is a crucial element in optical communication systems in order to increase transmission performance. In this paper, an all-optical 2R regenerator is implemented by self-phase modulation (SPM) based spectral broadening and offset filtering. Design calculations of the required parameters for the proposed 2R regenerator are carried out. Simulation results in terms of power transfer and bit error rate (BER) measurements are shown to prove the effectiveness of the proposed system. After the optical signal has been degraded by 500 km- long transmission span, the 2R regenerator in this work can reshape the degraded signal by achieving only 0.3dB power penalty at BER of 10^{-9}.

Keywords: *all-optical 2R regeneration, self-phase modulation, reshaping, offset filtering*.

1. Introduction

Optical fibre communication system has become popular nowadays with its advantages of high speed (>100Gbps) and long distance transmission. Indeed, the optical signal may undergo various degradations such as dispersion, polarization mode dispersion, nonlinear effects, and amplified spontaneous emission (ASE) noise during its propagation. To overcome these impairments, regenerators will be needed. All-optical regeneration technique had better be used for high speed operation capability and flexibility. Although all-optical 3R (Reamplification, Reshaping, and Retiming) regenerators are greatly interested, 2R (only Reamplification and Reshaping) regenerators can be used beneficially in medium distance transmission system.

Different all-optical regenerations based on nonlinear effects such as self-phase modulation (SPM)[1], cross-phase modulation (XPM)[2], and four-wave mixing (FWM)[3] have been demonstrated. Among them, SPM based 2R regenerator (proposed by Mamyshev) is progressively more attractive due to its experimental setup simplicity. In this work, self-phase modulation based 2R Regenerator for 10Gbps RZ with a duty cycle of 33 percent signal is implemented, combining with signal degradation stage to analyze its performance. A signal is passed through the transmission fiber that is 500km-long and then the degraded signal is regenerated via the proposed 2R regenerator. The performance of 2R regenerator is evaluated by the power transfer function curve and BER curve.

This paper is organized as follows: Section 2 describes principle of 2R regeneration by self-phase modulation and offset filtering. In section 3, design of the proposed 2R regenerator is mentioned. Section 4 explains simulation results and finally the paper is concluded in section 5.

2. Principle of 2R regeneration by self-phase modulation and offset filtering

The operation principle of the proposed design work is illustrated in Fig [1]. It includes signal transmission, signal degradation to prove the performance of regenerator, signal regeneration by means of self-phase modulation based 2R regenerator, and receiver. In signal degradation, dispersion compensation is done by dispersion compensating fiber after single mode fiber. A couple of amplifier and optical bandpass filter is used after each type of fiber length respectively to recover the fiber losses and to reject the spontaneous noise. Then the signal becomes distorted because of ASE noise caused by EDFA. Each transmission span consists of 100km-long single mode fiber and the signal is degraded by 5 transmission spans (i.e, 500km-long SMF). Signal degradation part in this work is considered to be almost the same as the actual optical signal transmission in the real world.

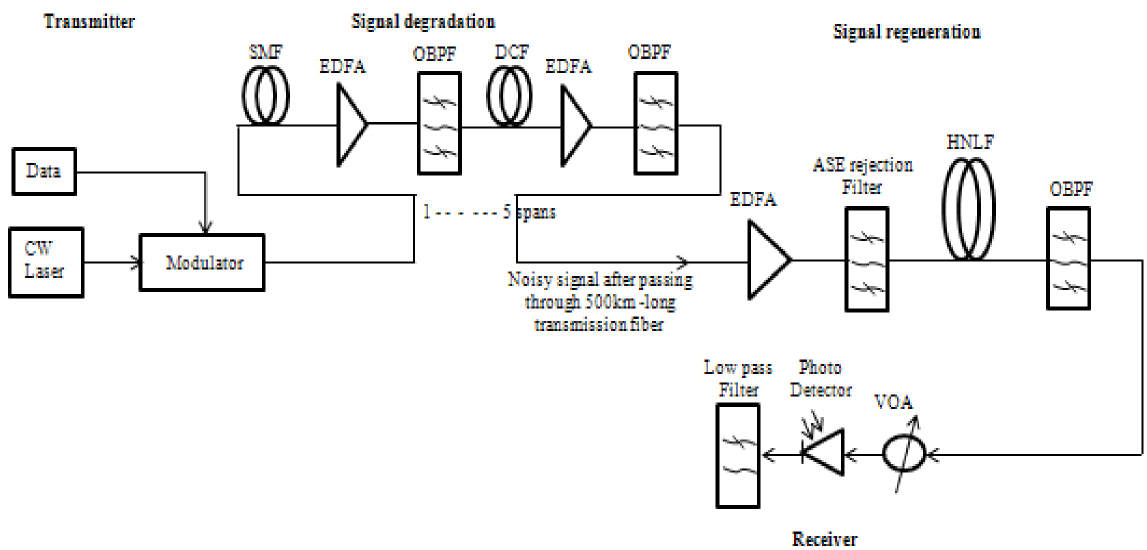

Fig.1. Block diagram of the proposed design work

In regeneration, the degraded optical data streams are first fed into an Erbium doped fiber amplifier (EDFA) in order to reach the required power for '1' symbol. An additional optical bandpass filter is inserted after the amplifier to reject the out-of-band ASE noise. The amplified signal is passed through the highly nonlinear fiber (HNLF). The HNLF produces SPM induced spectral broadening when the signal reaches high enough peak power. At the output of the HNLF, an optical bandpass filter (OBPF) is used as a reshaping element.

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The main function of 2R regenerator is the reshaping function. The optimum reshaping function depends on the SPM induced spectral broadening and position of offset filtering [4]. The broadening spectrum is directly proportional to the intensity of optical pulse [5]. When the low intensity pulses (or zero level noise) enter the HNLF, the spectrum broadening is small and it does not pass through the passband of OBPF. When the high intensity pulses (or one level noise) enter the HNLF, the spectrum broadening is large enough to extend over the passband of OBPF. Thus, the amplitude noise in the one and zero level can be suppressed by means of optical filtering.

Low level noise can be suppressed with large enough filter offset [4]. To reduce high level noise, the spectrum must be as flat as possible [6]. The fiber that has normal dispersive value (i.e D<0) can provide the flat spectral broadening in the presence of noise [7]. The optimum reshaping performance offers a step-like power transfer function. Fig.2. shows the ideal power transfer function of reshaping stage. If noise is taken into account, different power transfer function curves will be obtained. Flat top region of power transfer function curve can determine the performance of regenerator [8].

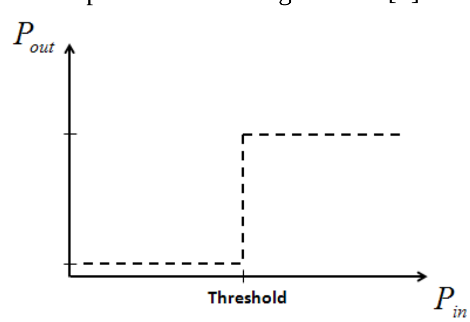


Fig.2. Illustration of an ideal step-like power transfer function

3. Design of the proposed 2R regenerator

The proposed regenerator is implemented by using a 1.5km long highly nonlinear fibre with a dispersion D of -7.2ps/nm/km, a nonlinear coefficient γ of 12.6W^{-1} km^{-1}, and attenuation α of 0.47dB/km. It contains a high power EDFA with a noise figure NF of 4dB. The ASE rejection filter with a Gaussian shape has a spectral width of 75GHz and centre frequency is located at the signal wavelength (λ_0).

IJCEM International Journal of Computational Engineering & Management, Vol. 17 Issue 3, May 2014
ISSN (Online): 2230-7893
www.IJCEM.org

When 1.025W (25.292dBm) peak power (P_0) is launched into the highly nonlinear fiber, the spectrum is broadened due to self-phase modulation effect inside the fiber. The maximum spectrum broadening can be calculated as:

$$\Delta\omega_{max} = 0.86\ \Delta\omega_0\ \Phi_{max} \qquad (1)$$

where, $\Phi_{max} = \gamma P_0 L_{eff}$, $\Delta\omega_0 = T_0^{-1}$,T_0=1/e intensity at half width and $T_{FWHM}=1.665T_0$ for Gaussian pulse. Then Eq(1) can be written as:

$$\Delta\omega_{max} = \frac{1.4319 P_0 L_{eff}}{T_{FWHM}} \qquad (2)$$

$$\Delta\omega_{max} = \frac{1.4319 P_0 L_{eff}}{2\pi T_{FWHM}} \qquad (3)$$

where, $L_{eff=}$ effective length, T_{FWHM}= pulse width at full width at maximum

= 124.9GHz

The broadened spectrum contains many peaks. The outermost peak is the most intent [5]. The filter offset has to select the outermost peak. The wavelength offset coincided with the outermost peak in the broadened spectrum is calculated as:

$$\Delta\lambda_{max} = \lambda^2/c\ \Delta f_{max} \qquad (4)$$

= 1nm, where the wavelength λ of the optical signal is 1550nm.

In this design, more power is needed (P_0=1.2182W, 26.042dBm) to get the accurate peak offset value. This is due to attenuation and dispersion effect in HNLF. For the regenerated pulse width to be the same as input pulse width, the bandwidth of offset filter can be design as:

$$\Delta\omega T_0\ (1/e\ \text{point}) = 1 \qquad (5)$$

$$\Delta\omega T_0\ (\text{FWHM}) = 2.77443$$

$$\Delta f_{(FWHM)} = \frac{0.4412}{T_{0(FWHM)}} \qquad (6)$$

= 13GHz

4. Simulation results

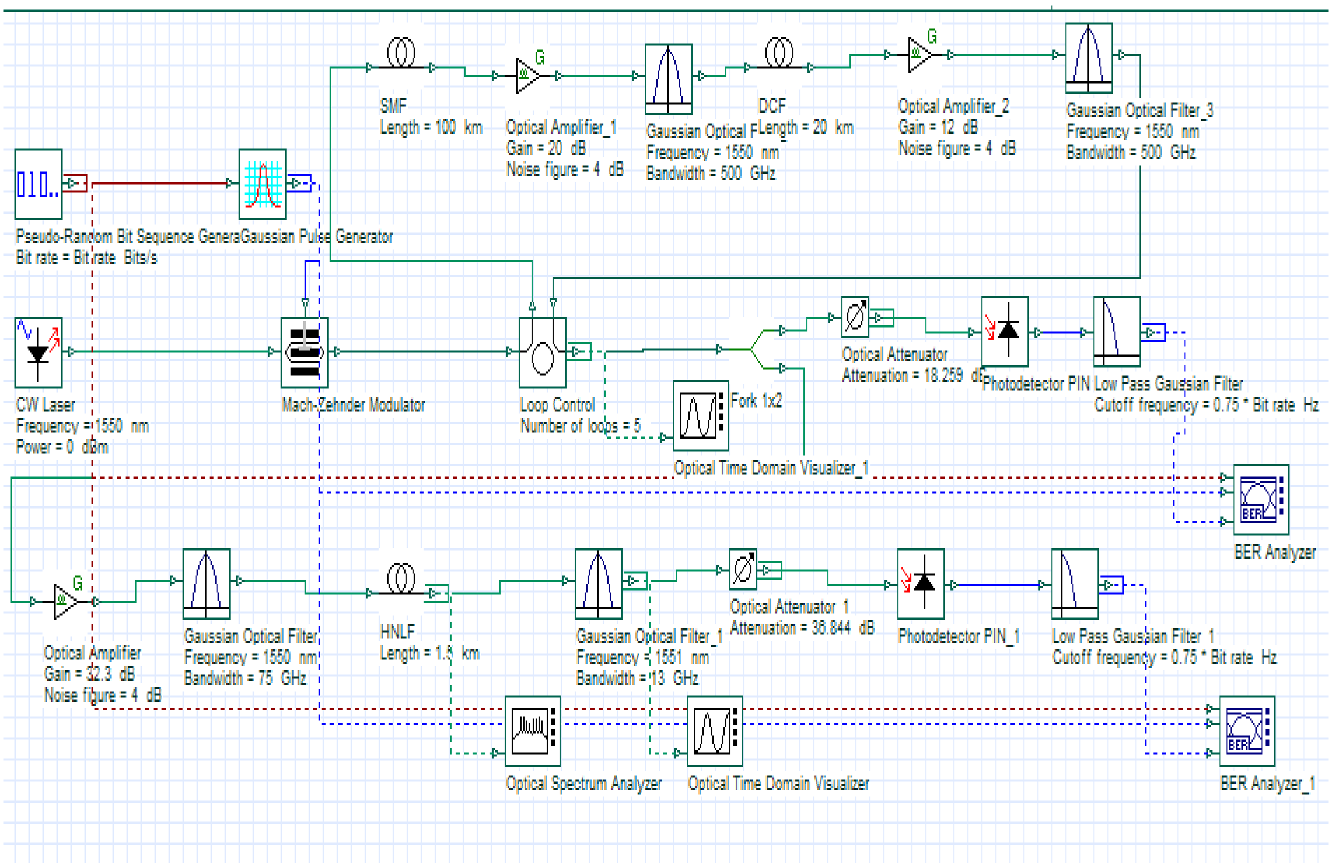
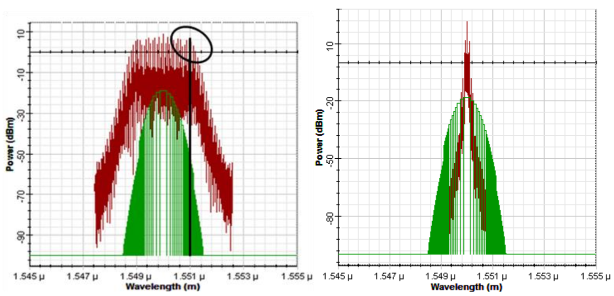


Fig.3. Simulation setup of the proposed system

Simulation setup of the proposed regenerator by using OptiSystem Software is depicted in Fig.3. The CW laser and 10Gbps RZ Pseudo Random Bit Sequence signal is modulated by Mach-Zehnder Modulator and then is sent to the transmission span. In the bit sequence, each '1'bit contains a Gaussian pulse with a full-width at half maximum (FWHM) of 33ps (typical pulse width for 10Gbps RZ signal) at a carrier wavelength of 1550nm. The transmission span is considered by a circulating loop. The loop is composed of 100km-long single mode fiber (SMF) with an anomalous dispersion of 16ps/nm/km, a dispersion slope of 0.08 ps/nm^2/km, a nonlinear coefficient of 1.3W^{-1}km^{-1}, and attenuation of 0.2 dB/km. Total loss is recovered by EDFA with 20dB gain. Dispersion is compensated by using dispersion compensating fiber with a length of 20km, a normal dispersion of -80ps/nm/km, a dispersion slope of -0.5 ps/nm^2/km, a nonlinear coefficient of 5.2 W^{-1}km^{-1}, and an attenuation is 0.6dB/km. To recover the fiber loss, EDFA with 12dB gain is used. Both amplifiers have noise figure of 4dB.These two amplifiers are followed by OBPF with a spectral width of 500GHz to remove ASE noise added by amplifiers. The signal is passed through in circulating loop for 5 times in order to degrade its performance.



(a) (b)

Fig.4. (a) The spectrum of the degraded signal, and (b) The broadened spectrum induced by SPM effect

Fig.4 shows the spectrum of the degraded signal before highly nonlinear and after highly nonlinear fiber. In Fig.4 (b), the spectrum is wider than that in Fig.4 (a) because of the self-phase modulation effect inside the highly nonlinear fiber. The OBPF selects the dominant spectral peak in the broadening spectrum. It changes from the original center wavelength.

Fig.5 (a) is an input signal waveform of 10Gbps RZ signal and Fig.5 (b) is the degraded signal after 500km transmission fibre. Fig.5(c) shows the output signal after 2R regeneration. It can be seen that the regenerated output waveform is nearly the same as the input waveform.

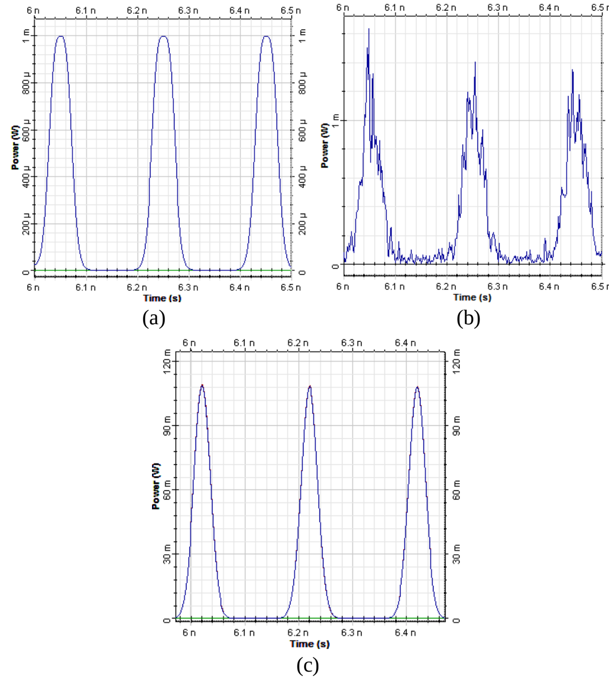


Fig.5.Waveforms for (a) Transmitted signal, (b) Degraded signal, and (c) Regenerated signal

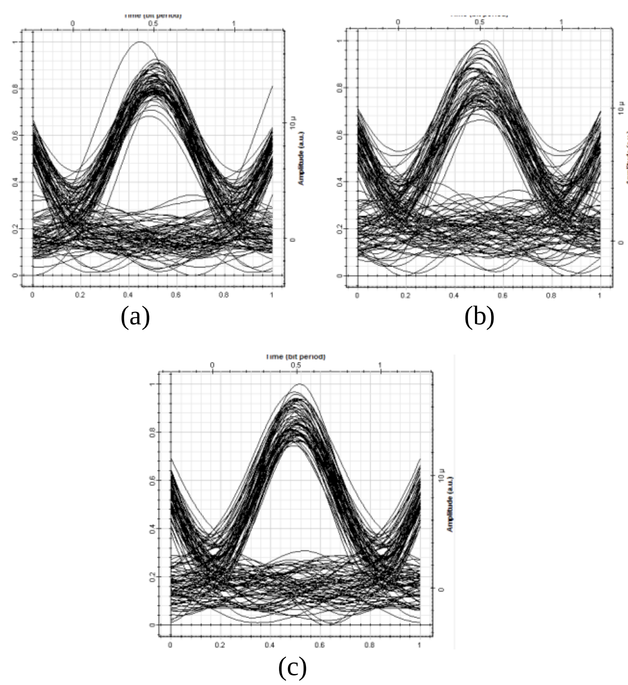


Fig.6.Eye diagrams for (a) Back to back system, (b) without regenerator after passing through 500km transmission fiber, and (c) after regeneration at approximately 10^{-9} BER

Eye patterns of the original input signal, degraded signal and regenerated signal are compared in Fig.6. As seen in Fig.6 more eye opening (hence higher extinction ratio) is observed in the regenerated signal (c) than the degraded signal (b).

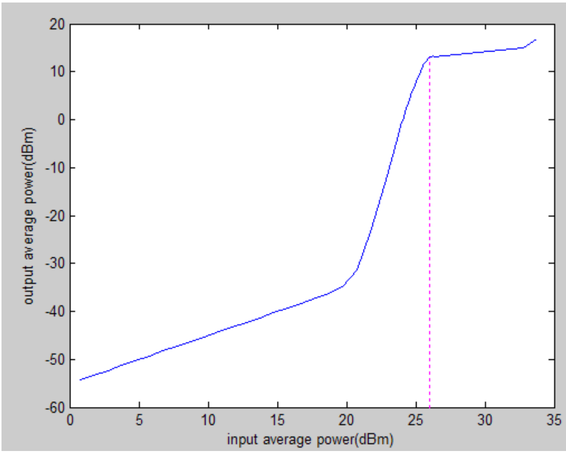


Fig.7. Power Transfer function of the 2R regenerator

Fig.7 depicts the power transfer function of the designed 2R regenerator. Although it is not exactly the same as the ideal step-like power transfer function which is shown in Fig.2, it does have reshaping property. 'One' level noise can be suppressed in the flat-top region which is around the input average power of 26dBm.

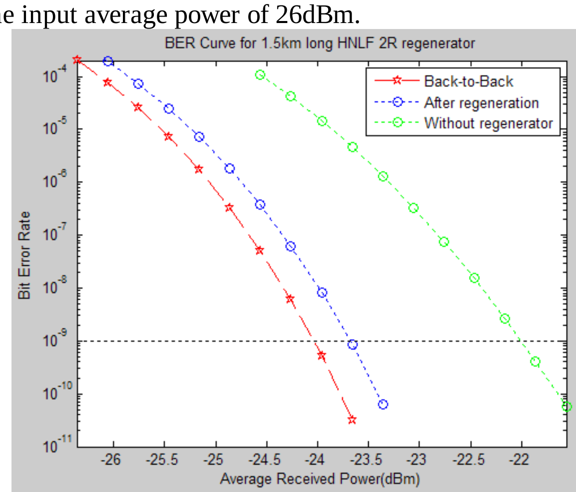


Fig.8. BER measurements for 2R regenerator

Bit error rate (BER) measurements for the back-to-back case, the degraded signal and regenerated signal are illustrated in Fig.8. As seen in Fig.8, the power penalty of the regenerated signal is only 0.3dB at standard BER of 10^{-9}.

5. Conclusion

In this work, SPM induced spectrum broadening and offset filtering based 2R regenerator is designed and implemented. The regeneration performance is expressed in power transfer function and BER measurement.. In this system, the flat-top region is achieved at input average power around 26dBm. Power penalty for 2R regeneration is 0.3 dB only.

Acknowledgments

The author is deeply grateful to her teachers, Department of Electronic Engineering, Mandalay Technological University, Myanmar.

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