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ORIGINAL ARTICLE

Design and Development of 60 Gb/s DPSK Transceiver System for Renewal of Optical Signal

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ABSTRACT

The renewal of optical degraded signals via all-optical or electronic mean are recent trends in the field of Nonlinear optics. The signal regeneration is now the center of attraction for many application in communication such as; Internet of Things (IoTs) and Big Data over long haul communication systems. This paper describes the technique based on the renewal of the optical degraded signal for DPSK transceiver system. The designed optical signal renewal technique is fully capable to provide the effective noise mitigation for the signal transmitted over a noisy long-distance fiber link. The developed technique also provides the BER of 10-11 with 6 dBm power improvement for the regenerated signal. The system is designed and developed using MATLAB in Simulink model. The designed system can be used in the existing long-haul communication systems in order to achieve noiseless communication.

Keywords: BER, Constellation diagram, DPSK System, Optical Signal Processing. Optical Signal Renewal Technique

Author`s Contribution
[1,2,3,4]*Manuscript writing, Data analysis, interpretation, Conception, synthesis, planning of research, Interpretation and discussion, Data Collection*

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INTRODUCTION

Optical Fiber system is mainly used for the long haul communication. The main applications of the optical systems are its wide bandwidth, less effected to noise, and attain higher data rate [1]. However, during the long haul communication, there are several parameters that restrict the performance of the system. Such as; amplitude noise, phase noise, and ASE noise [2]. These noises should be mitigated in order to provide noiseless communication. For the mitigation of aforementioned noises, optical amplifiers and regenerators are used. These devices provide the function of noise mitigation via O-E-O conversion mechanism [3]. Among these devices, the regenerator is most significantly used in long haul communication. There are mainly two types of regenerator based on characteristics of the signal. In the electrical domain, the optical to electrical and electrical to optical conversion is required [4]. While in the optical domain there is no conversion requirement. Both of these techniques have their own advantages and disadvantage [5]. It has been reported that during the high-speed transmission of more than 10 Gb/s signal at high transmission distances, the signal quality is lost, in result, the degradation in BER is attained. Furthermore, the quality of transmission is also degraded [6-10]. Existing optical signal regenerators support only a limited data rate of 10 Gb/s with limited BER [21-22]. In the next, related work is discussed, in which existing signal renewal systems are discussed along with the some features of designed system.

LITERATURE REVIEW

Nonlinear signal processing provides an opportunity to improve the system's performance for the noisy optical fiber link [1-3]. Currently, several research studies have been carried out for improving the performance of the noisy long haul communication systems. In result, reduce in amplitude and phase noises are attained [4-7]. In some cases, the reduction in either phase noise [8-10], or in the combined effect of amplitude and phase noises [11-13] for different modulation schemes such as; Phase Shift, Differential Phase Shift and others are addressed. The Phase Shift Scheme is more resilient to noise, due to 3-dB receiver sensitivity [14-15]. The presented signal renewal techniques in [16-20] have several issues such as; high power consumption, low Q-Factor, Low BER. These techniques utilize dual high pumps, additional circuitry such as; clock recovery and etc. These techniques produce complication in system design and purpose of quality transmission remain unaddressed somehow [23-24]. It has been discussed by Yaqoob S. in [25] that optical renewal at 10Gb/s data rate or more have high power penalties.

This work demonstrates a new optical signal renewal technique that offers the mitigation of noises for Differential Phase Shift systems. The developed technique offers low BER along with low power consumption in comparison to the existing work [21-25].

RESEARCH METHODOLOGY

- **Design of New optical signal renewal technique for 60 Gb/s DPSK transceiver System**

In this work, a new optical signal renewal technique is aimed for 60 Gb/s DPSK transceiver system that regenerates the degraded transmitted signal propagated over a noisy link of 300 km fiber link. The system model is presented in Fig. 1 that describes the development phases of the optical signal renewal technique.

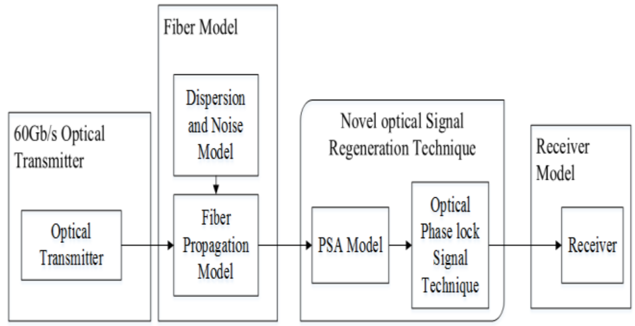

Fig. 1 Design and Development of New optical signal renewal technique for 60 Gb/s transceiver system

In the First stage, as shown in Fig. 1, the 60 Gb/s optical transmitter model is shown. In the second stage, the noisy long distance single mode fiber link is designed. In the Third stage, the developed new optical signal renewal technique is used to remove the noises for the noisy 60 Gb/s optical signal that traveled from the 300 km. In the final stage, the receiver model is developed for analyzing the performance of the designed system.

a. Design Stage 1: 60Gb/s Optical Transmitter

The designed optical transmitter consists of the binary input sequence, carrier signal and an optical modulator that converts electrical data signal in the optical signal. In this work, 60Gb/s optical DPSK transmitter is designed as shown in Fig. 2 that contains PRBS random sequence, DPSK generator, laser carrier signal, and modulator to convert PRBS-DPSK electrical signal into an optical signal.

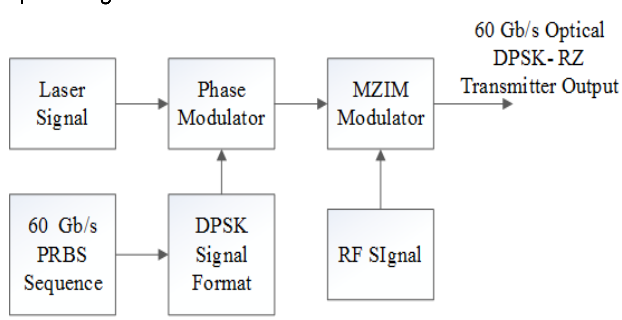

Fig. 2 Model for 60 Gb/s optical DPSK-RZ transmitter

b. Design Stage 2: Propagation of 60Gb/s optical DPSK optical signal over SMF

Single Mode Fiber (SMF) is designed via Split Step

Fourier Method (SSFM) that uses Nonlinear Schrödinger Equation (NLSE). The single mode fiber is designed in MATLAB [26]. Equation (1) defines the SMF design layout [27];

$$\frac{\partial A(z,t)}{\partial z}+\frac{\alpha}{2}A(z,t)+\beta_1\frac{\partial(z,t)}{\partial t}+\frac{i}{2}\beta_2\frac{\partial^2 A(z,t)}{\partial t^2}-\frac{1}{6}\beta_3\frac{\partial^3 A(z,t)}{\partial t^3}=\gamma\left|A(z,t)\right|^2 A(z,t) \tag{1}$$

Where, z is the spatial coordinate for fiber attenuation, β_1 defines the group delay, β_2 and β_3 defines the second and third-order terms for dispersion, γ is the nonlinear coefficient. The fiber dispersion model is carefully designed for SMF model to produce Inter-Symbol Interference (ISI) for injecting amplitude and phase noise [28]. These fiber dispersion model terms include with the SMF model for developing the noisy fiber link. NLSE equation after including fiber dispersion model and noise model will attain Equation (2) [27]

$$\begin{aligned}&\frac{\partial A(z,t)}{\partial z}+\frac{\alpha}{2}A(z,t)+\beta_1\frac{\partial(z,t)}{\partial t}+\frac{i}{2}\beta_2\frac{\partial^2 A(z,t)}{\partial t^2}-\frac{1}{6}\beta_3\frac{\partial^3 A(z,t)}{\partial t^3}\\&+(-5\cdot\log(1-(4\cdot b\cdot(D_M+D_W+P_D)\cdot L\cdot\sigma))\\&=\gamma\left|A(z,t)\right|^2 A(z,t)\end{aligned} \tag{2}$$

The 60Gb/s DPSK-RZ optical signal $S(t)$ is generated using the model in Fig. 2. The signal will be propagated over noisy fiber optic link, this will alter the equation (2) and will yield equation (3) [27];

$$\begin{aligned}&\frac{\partial S(z,t)}{\partial z}+\frac{\alpha}{2}S(z,t)+\beta_1\frac{\partial(z,t)}{\partial t}+\frac{i}{2}\beta_2\frac{\partial^2 S(z,t)}{\partial t^2}-\frac{1}{6}\beta_3\frac{\partial^3 S(z,t)}{\partial t^3}\\&+(-5\cdot\log(1-(4\cdot b\cdot(D_M+D_W+P_D)\cdot L\cdot\sigma))\\&=\gamma\left|S(z,t)\right|^2 S(z,t)\end{aligned} \tag{3}$$

There are higher dimensional analogs of equation (3) and propagation in fiber is a phenomenon that occurs naturally in time and one spatial domain [27]. Equation (3) states the signal received at the end of over noisy fiber optical channel, the fiber length can be changed by configuring the fiber length parameter. In this work, the transmission distance is set to 300 km. In the next, the new optical signal renewal technique is implemented to regenerate 60 Gb/s degraded optical transmitted signal.

c. Design Stage 3: Design and Development of New Optical signal renewal Technique

The developed optical signal renewal technique mitigates the noises from the degraded signal. The optical signal renewal technique is designed via Phase Amplification (PA) and optical lock signaling mechanism to regenerate the degraded signal. Using saturation and reshaping, phase and amplitude noises are mitigated. In the optical signal renewal designed technique, the 60Gb/s degraded signal is mixed with a pump signal and are inserted into HNLF fiber to regenerate multiple frequency components along with degraded signal with high gain at different frequency. The other frequency components are removed via optical filtering. In the signal renewal technique, the separation of the pump and other frequency components is performed. The regenerated signal is produced at a new wavelength with in-phase gain. The filter output that yields the renewal of signal with in-phase gain information is given to decision block (phase detector). After that using the reshape function, the changes in the dimension of the signal to smoothen rough edges of renewed signal with in-phase gain is performed. In the last, the Receiver model is designed to analyze the results of designed optical signal renewal technique via BER and constellation diagram.

Simulation Setup for Novel all-optical signal regeneration Technique using MATLAB Simulink

The simulation setup of the developed optical signal renewal technique for 60 Gb/s DPSK transceiver system is depicted in Fig. 3.

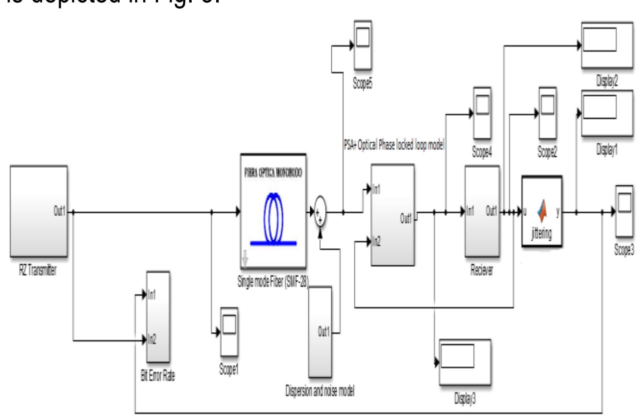

Fig.3 MATLAB Simulink model for the developed optical signal renewal technique for 60 Gb/s DPSK transceiver system

The 60Gb/s PRBS DPSK Signal is developed using PRBS sequence in MATLAB and combined with the Laser carrier signal. The signal is transferred to noisy Single mode fiber of 300 km. After that signal is given to the developed optical signal renewal technique to remove the noises from the degraded signal. The optical lock signal mechanism is designed using MZIM. The frequency of MZIM falls in the same range of as of degraded signal. In order to produce the zero error phase both the frequencies i.e signal of degraded signal and MZIM should be same. There will be zero error at the output that defines the signal phase lock condition. The regenerated signal is often delayed due to filter components. In this case, it is necessary to remove the delay from the regenerated signal. For this purpose, the regenerated signal is investigated for the delay. If the signal has no delay with respect to the input signal, the signal is directly given to the performance evaluation block. If the signal possesses delays, it can be removed using CRICSHIFT MATLAB function. In the next, the discussion over attained results is discussed in detail.

RESULTS AND DISCUSSION

The performance evaluation of the designed system for noisy 60Gb/s DPSK signal is performed at receiver's end. The degraded optical signal received at the end of 300 km noisy link of fiber is shown in Fig. 4. It can be seen that in the small amplitude ranging from (-30 to -40) lots of jitters are expiated.

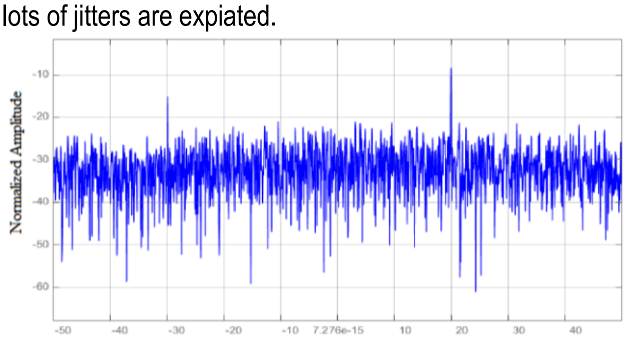

Fig.4 The 60Gb/s noisy optical signal received after 300 Km.

The signal regeneration using the developed technique is initiated by feeding this degraded signal shown in Fig. 4 along with the pump signal to perform the phase sensitive amplification using HNLF fiber. The PSA performance is analyzed for different values for $|u(z)|$ hat reveals the phase regenerative property of PSA. The proper values achieved for $|u(z)|$ are fall in between 0.5 to 2.1 and the value selected for this specific case is 0.6. The relative power of input is balanced based on power induced in HNLF. These power remain as 12 dBm and -6 dBm respectively, with fix value of $|u(z)|$ as 0.6. During FWM, the various components are produced at different or at the same frequency. The pump signal, if not depleted that means $\omega_i = 2\omega_p - \omega_s$ is quite weak. Due to this, 4 dB gain of PSA is achieved for the signal. The optical phase locked signal and saturation block significantly reduces the phase noise from the PSA signal. It is extracted that 90% phase noise is alleviated as illustrated in Fig. 5.

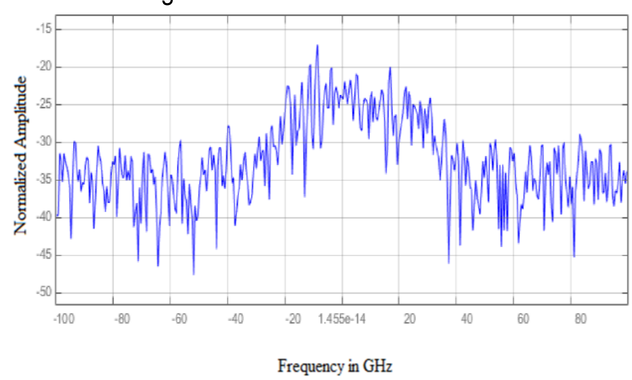

Fig. 5 Response of phase and noise mitigation using the designed technique

From Fig.5, it can be realized that the signal still possesses the amplitude noise as the signal has sharp edges. In order to mitigate the amplitude noises, reshape function is used that changes the signal dimensionality to acquire the smooth edges signal. The response of amplitude noise mitigation is defined in Fig. 6.

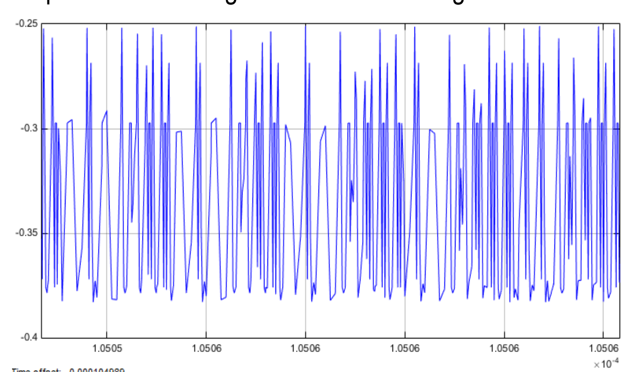

Fig. 6 Response of amplitude noise mitigation using a designed technique

The performance of the developed optical signal renewal technique is analyzed using the BER and constellation diagram. BER curves are calculated using Monte Carlo simulations of the input (at the end of fiber link) and outputs (at end signal regeneration technique) signals. Fig. 7 demonstrates the BER curves that are attained before and after applying the developed optical signal renewal technique. It is extracted that designed technique has achieved BER lower than 10-11 at low power penalty in comparison to the degraded signal. The designed regenerator is fully proficient of restoring the data reliability.

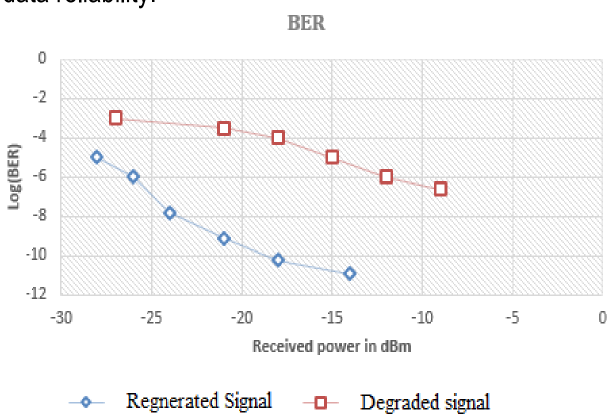

Fig. 7 Results attained in terms of BER, before and after the developed optical signal renewal technique

The developed optical signal renewal technique provides the performance improvement in phase response in the presence of strong phase noise (included during dispersion and noise model). Fig. 8 to Fig. 11 defines the phase response in terms of constellation diagram at different stages.

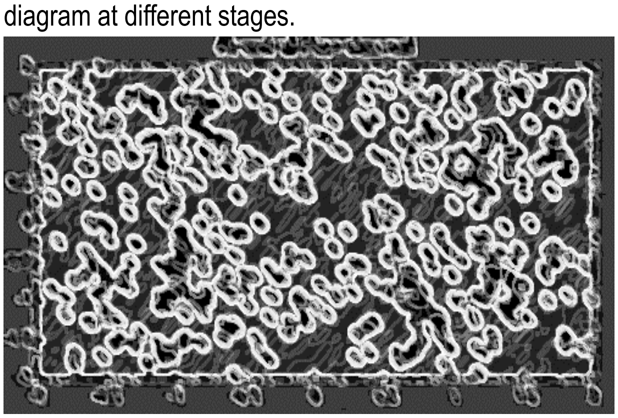

Fig. 8 Constellation Diagram at Fiber End

Fig. 8 represents the constellation diagram when the signal is received at the end of a noisy fiber link of 300 km in length. It can be seen that phase response is scattered due to transmission impairments.

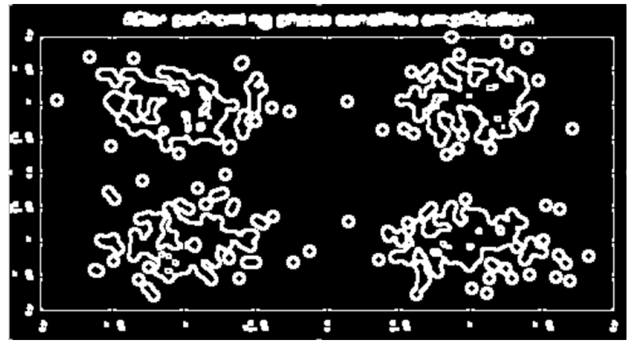

Fig. 9 Constellation Diagram at after Phase amplification

Fig. 9 presents the constellation diagram at the end of phase sensitive amplification, the major challenge of getting the frequency condition $\omega_i = 2\omega_p - \omega_s$ is achieved and the signal is regenerated with an in-phase gain of 4 dB.

Fig. 10 illustrates the constellation diagram at end saturation block that mitigates the phase error (produced using an optical phase-locked signal and regenerated signal). Fig. 11 shows a constellation diagram at the end of the reshaped function that mitigates the amplitude noise.

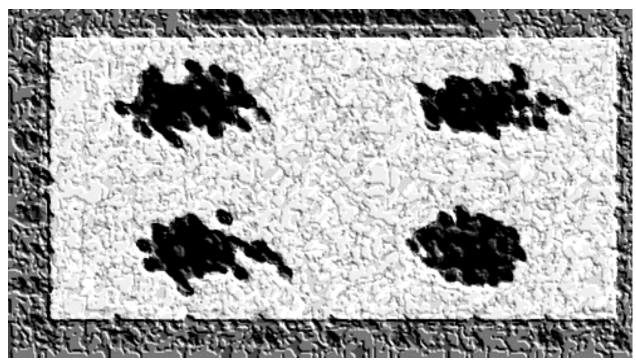

Fig. 10 Constellation Diagram at after removing the phase error

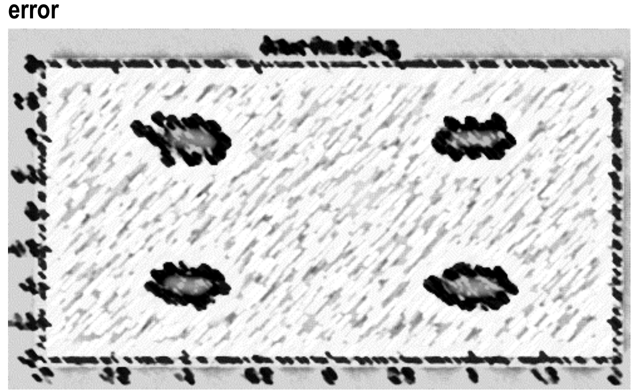

Fig. 11 Constellation diagram before and after designed optical signal renewal technique

In results, it is defined that the designed optical signal renewal technique has achieved the low BER at low power consumption for 60Gb/s optical DPSK system for regenerating the signal by alleviating the noises from the signal.

CONCLUSTION

In this work, a new optical signal renewal technique is designed that regenerates the signal with phase and amplitude noise mitigation for 60 Gb/s DPSK transceiver system. The designed system enables the restoration of the degraded signal fidelity up to BER of 10-11 for input BER of 10-7.

The designed optical signal renewal technique offers the in-phase gain of 4 dB using phase amplification and saves power penalty of more than 6 dB in addition to low BER. The designed optical signal renewal technique is significantly mitigating the phase and amplitude noise up to 90% from the degraded signal propagated at a noisy fiber link of 300 km.

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