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Research Article

DEVELOPMENT OF OPTICAL SIGNAL REGENERATION TECHNIQUE USING ULTRASCALE FIELD PROGRAMMING GATE ARRAY

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ABSTRACT

The optical signal regeneration is a demanding research area for long-haul optical communication systems. The existing optical signal regeneration techniques are not facilitating for low BER in real-time. In this paper, a new optical signal regeneration technique is developed that provides low BER in real-time for 10Gb/s optical degraded signal for Differential Phase Shift Keying (DPSK) signal at different transmission distances between 50 km to 250 km. The developed optical signal regeneration technique has achieved a very low Bit Error Rate (BER) of 10^{-13} at low received the power of -17 dBm averagely for DPSK signal at different transmission distances experimentally via UltraScale FPGA.

Keywords: Bit Error Rate (BER); Differential Phase Shift Keying (DPSK) signal; Optical Signal Regeneration, Field Programming Gate Array.

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1. INTRODUCTION

The performance of high-speed optical systems is limited due to the collective effect of amplifier noise accumulation, chromatic and polarization-mode dispersion, fiber nonlinearity, inter-channel crosstalk, multipath interference, long distance, transmission of high power and frequency signal, and other impairments. The mitigation of transmission impairments and noise from transmitted signal is termed as signal regeneration. However, signal regenerators have the limited capabilities such as the ability to be used in different transmission for real time link speed of few Gb/s data rate for 10Gb/s are still challenging for higher order modulation formats such as; DPSK, QAM and etc. [1-3]. Currently, optical signal regeneration is achieved using nonlinear signal processing [4]; that offers parametric amplification via Self Phase Modulation (SPM), Cross Phase Modulation (CPM), and Four Wave Mixing (FWM) using different types of fiber such as Highly Nonlinear Fibers (HNLF), microstructure fiber, and non-silica fibers [5-6]. Several problems are also reported with existing optical signal regeneration system such as; requirements of the data rate of the input signal, narrow linewidth, and high power pumps that are phase locked to the signals (and idlers) [7-11]. Recent issues are explored in [12-13]; such as power consumption and experimental demonstration for optical signal regeneration systems. In this paper, a new optical signal regeneration technique is developed to perform signal regeneration for the high-speed degraded signal for DPSK signal. The designed system consumes less power and offers low BER with low received power.

2. DESIGN METHODOLOGY

The system model of the designed optical signal regeneration technique is composed of Phase Sensitive Amplification (PSA) model, Optical Locked Model Frequency, and noise mitigation model as shown in figure 1. The system model illustrates that high data rate 10 Gbps degraded input signal coming from noisy fiber link is injected into Highly Nonlinear Fiber (HNLF) along with high-frequency pump source. This will generate different spectral components along with a regenerated in-phase gain signal for a degraded signal at a new wavelength. The output of HNLF fiber is passed through an optical filter that separates regenerated in-phase gain regenerated signal from the pump signal, the idler signal, and from other frequency mixing products. The regenerated signal's frequency is optically locked with the signal generated using designed optical frequency locked model.

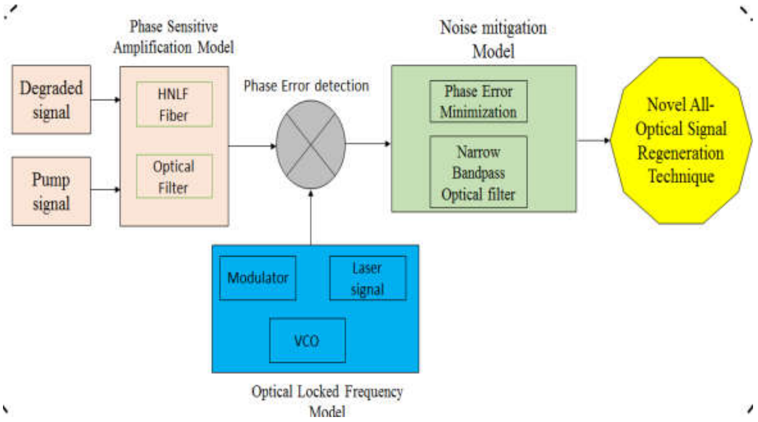


Fig.1. System model for the developed optical signal regeneration technique

The designed optical frequency locked model detects the phase error/difference between both the signals (regenerated and optical locked signal) using detector block. The noise mitigation mode reduces the detected phase error using phase error minimization algorithm. The regenerated in-phase gain signal with minimized phase error is passed through another optical bandpass filter (OBPF) having a narrow passband that mitigates the remaining phase error/noise and amplitude noise occurred during regeneration and locking mechanism. The Phase Sensitive Amplification (PSA) is achieved using degenerated FWM that possess the third order nonlinearity via HNLF fiber. Using modified coupled mode equation, the PSA gain is calculated as shown in (1);

$$G_{PSA} = 1 + \left\{ 1 + \frac{4\gamma^2 P_P \eta^2 + k^3 + 4\gamma k P_P \eta \cos\theta}{4g^3} \right\} \sinh^2 gL + \frac{\gamma P_P \eta \sin\theta}{g} \sinh 2gL \quad (1)$$

The optical filtering is performed over the output of HNLF fiber to filter the regenerated PSA signal from the pump signal, idler signal and other frequency mixing products. The regenerated signal is filtered out using FIR optical filter. In FIR optical filter, single stage MA optical filter is used based on MZI. The regenerated signal is filtered out using MA optical filter transfer function as described in (2);

$$H_s(z) = A_s(z)\sqrt{1 - C_{R1}}\,\sqrt{1 - C_{R2}}\,e^{-i\left(\varnothing z^{-1} + \sqrt{C_{R1}C_{R2}}\right)} \quad (2)$$

where $H_s(z)$ is the filter transfer function to filter out the regenerated in-phase gain signal $A_s(z)$ from different spectral components, C_{R1}, C_{R2} are the coupling coefficients for the optical filters arm1 and arm2 respectively. The optical frequency locked signal model is used to generate an optical signal, which has locked frequency that has the same phase characteristics as of input optical signal (optical modulated signal transmitted at single model fiber channel) with the filter out regenerated in-phase gain PSA signal. The optical frequency locked signal model is realized using MZIM modulator, VCO, and a laser signal. The amplitude of the output signal is dependent on different signals such as; VCO, control signal, regenerated signal and on the total phase error $\varnothing_e(t)$. This phase error is minimized using AR optical filter. In the next section, the designed optical signal regeneration technique is implemented over DPSK- NRZ transceiver system for different optical fiber transmission distance using FPGA.

3. HARDWARE IMPLEMENTATION OF THE DEVELOPED OPTICAL SIGNAL REGENERATION SYSTEM

The developed optical signal regeneration technique for DPSK-NRZ transceiver system is implemented using Xilinx KCU105 UltraScale FPGA board that provides the optical interface in an embedded system. The developed optical signal regeneration is converted in HDL language. The results of the designed system are demonstrated using built-in GUI that provides live monitoring of BER, received power and serial IO analyzer. The system model for demonstrating the experiment of the developed optical signal regeneration technique for DPSK-NRZ transceiver system is shown in Fig. 2.

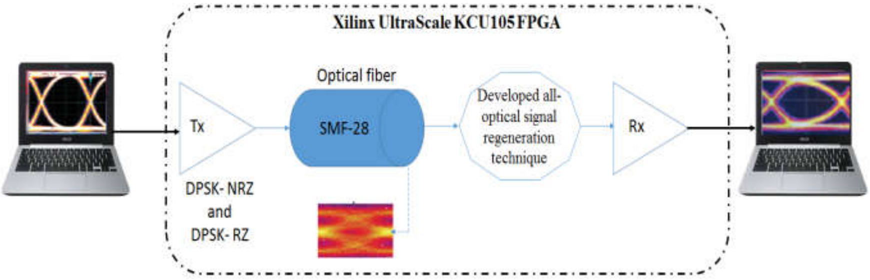


Fig.2. System model for experimental demonstration

The system model in figure 2 illustrates that at the transmission side, an electrical signal of 10Gb/s is transmitted using a computer, and this computer transfers the electrical signal using high speed USB connector Joint Test Action Group (JTAG) connector to Xilinx KCU105 UltraScale FPGA. The electrical signal is converted into an optical signal using HDL based optical transmitter designed using vhdl coding and the optical signal is transferred to noisy SMF-28 that is a built-in link available in Xilinx KCU105 UltraScale FPGA. The transmitted signal is corrupted due to transmission at long distance. The degraded signal is regenerated and noise is mitigated using the HDL based developed optical signal regeneration designed with vhdl code. The received signal is passed to another computer connected to a receiving end of Xilinx KCU105 UltraScale FPGA using another high-speed USB connector Universal Asynchronous Receiver/Transmitter (UART), accessible in Xilinx KCU105 UltraScale FPGA. The received signal is analyzed using GUI supported by Vivado suite available in Xilinx KCU105 UltraScale FPGA. After setting up the system, the designed HDL based developed optical signal regeneration for DPSK- NRZ transceiver system's RTL schematic diagram is opened in "Hardware Manager" of Vivado design suite. In the next, result attained for developed signal regeneration technique is demosntarted.

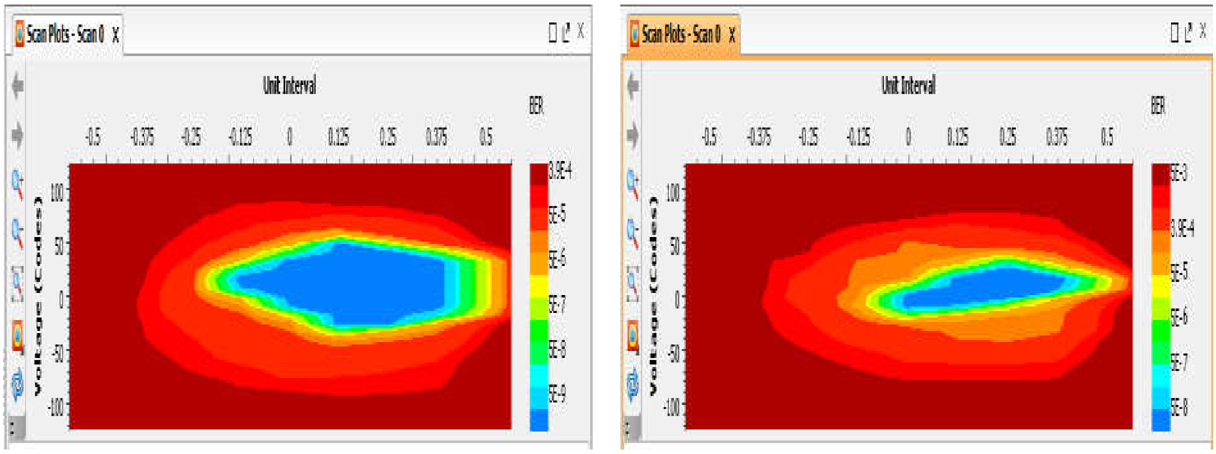
4. RESULTS AND DISCUSSION

The performance analysis of the designed system experiment is analyzed using built-in GUI in UltraScale Scale FPGA board. The designed DPSK-NRZ system for the developed optical signal regeneration technique is programed in Xilinx KCU105 UltraScale FPGA for different links. The different link defines the optical fiber distance used during the experiment. The GUI data observed before and after the developed optical signal regeneration technique for degraded DPSK-NRZ system for transmission links having a different distance of 50 km, 100 km, 150 km, 200 km, and 250 km. The DPSK-NRZ signal data signal is transmitted at different links such as Link found 0 is of 50 km, Link found 1 is of 100 km, Link found 2 is of 150 km, Link found 3 is 200 km, and Link found 4 is of 250 km as illustrated in Table 1.

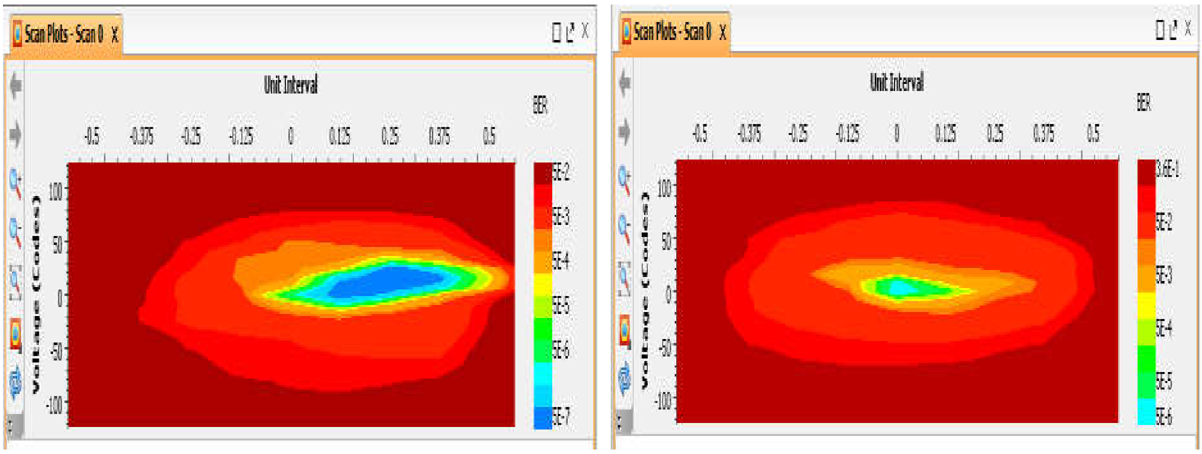
Table 1. Experimental analysis before implementing the developed optical signal regeneration technique over degraded links of DPSK-NRZ system

Link name	Link length in km	Max. BER	Received power in dbm
Link 0	50	10^{-9}	-11
Link 1	100	10^{-8}	-10
Link 2	150	10^{-7}	-9
Link 3	200	10^{-6}	-7
Link 4	250	10^{-5}	-6

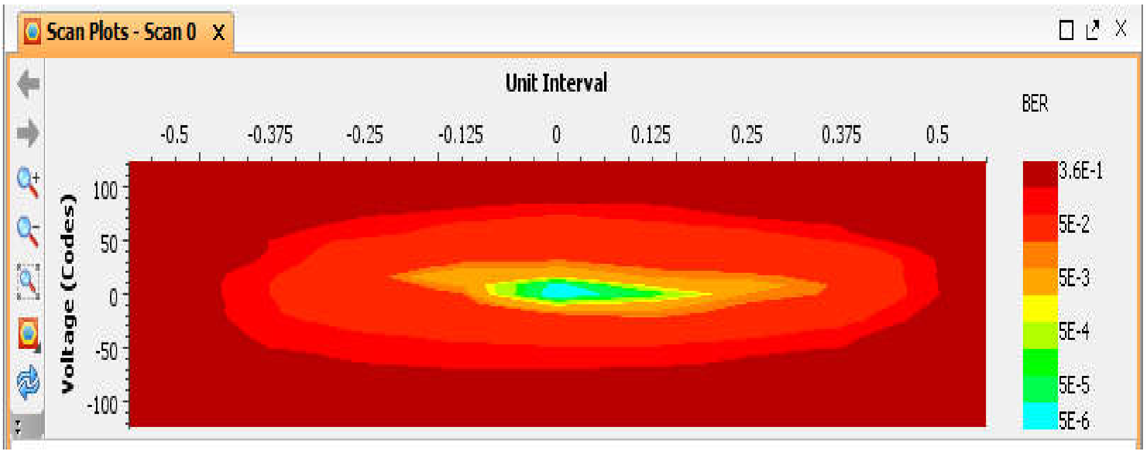
It is observed that when DPSK-NRZ signal is transmitted over noise optical fiber link for aforementioned distances without implementing the developed optical signal regeneration technique, the GUI data is recorded that defines the link speed, BER, and received power are shown in figure 3.



(a) (b)



(c) (d)



(e)

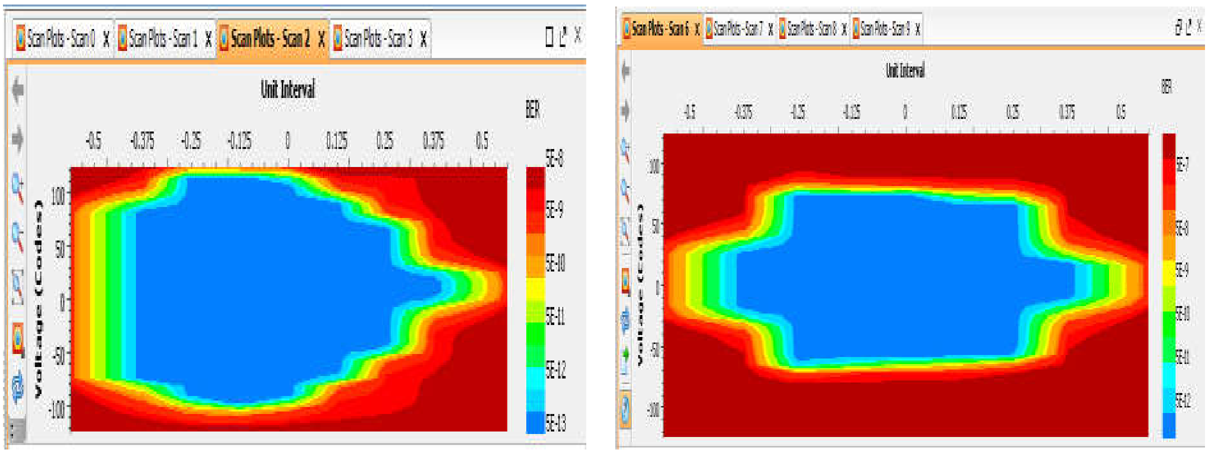
Fig.3. BER and IO diagram using serial IO analyzer for (a) 50 km, (b) 100km, (c) 150 km, (d) 200km, (e) 250km fiber link before implementing the developed optical signal regeneration technique for DPSK-NRZ system

It can be analysed from figure 3(a) that before applying optical signal regeneration technique the BER recorded is of 5E-9 depicted for 50 km of fiber link of link found 0. Similarly, for 100 km, BER recorded is of 5E-8 as shown in figure 3(b). For 150 km, BER recorded is of 5E-7 as shown in figure 3(c). For 200 km, BER recorded is of 5E-6 as shown in figure 3(d), for 250 km, BER recorded is of 5E-5 as shown in Fig. 3(e). It is defined that the UltraScale FPGA is programmed twice, one for degraded long distance fiber link without developed optical signal regeneration. The second is degraded long distance fiber link with developed optical signal regeneration when the developed optical signal regeneration technique is applied on above degraded links. The BER received power are illustrated after applying the developed optical signal regeneration technique over degraded links discussed in Table 2.

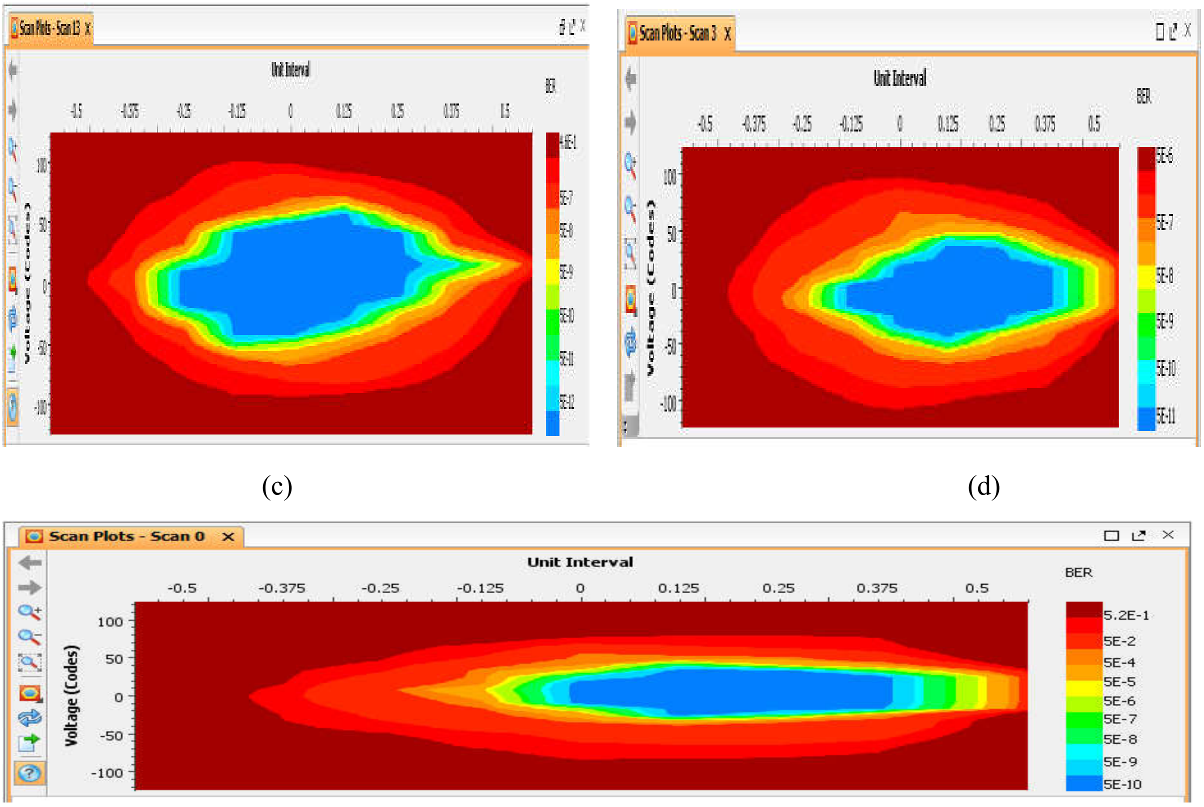
Table 2. Experimental analysis after implementing the developed optical signal regeneration technique over degraded links of DPSK-NRZ system

Link name	Link length in km	Max. BER	Received power in dbm
Link 0	50	10-13	-17
Link 1	100	10-12	-16.2
Link 2	150	10-12	-14.1
Link 3	200	10-11	-13.5
Link 4	250	10-10	-12.8

The BER and received is recorded for degraded links after applying the developed optical signal regeneration technique using GUI, significant improvement is achieved in BER, received power as demonstrated in figure 4.



(a) (b)



(c) (d)

(e)

Fig.4. BER and IO diagram using serial IO analyzer for (a) 50 km, (b) 100km, (c) 150 km, (d) 200km, (e) 250km fiber link after implementing the developed optical signal regeneration technique for DPSK-NRZ system

It can be analysed from figure 4 that after applying optical signal regeneration technique the BER recorded is of 5E-13 depicted as blue color for 50 km link as shown in figure 4(a). Similarly, for 100 km, BER recorded is of 5E-12 as shown in figure 4(b). For 150 km, BER recorded is of 5E-12 as shown in figure 4(c). For 200 km, BER recorded is of 5E-11 as shown in figure 4(d), for 250 km, BER recorded is of 5E-10 as shown in figure 4(e). It can observe from is illustrated in Table 5.2 that very low BER with significant power improvement is achieved for a designed system using the developed optical signal regeneration technique. The power penalty for degraded link 0, 1, 2, 3 and 4 is recorded as -11 dBm, -10 dBm, -9 dBm, -7 dBm and -6 dBm, respectively and after applying the developed optical signal regeneration technique to degraded links, the power penalty improved as -17 dBm, -16.2 dBm, -14.1 dBm, -13.5 dBm and -12.8 dBm for link 0, 1, 2, 3, and 4 respectively. It is demonstrated that developed optical signal regeneration offers the low BER at low received power for DPSK-NRZ degraded signal over a different fiber link.

5. CONCLUSION

In this paper, a new optical signal regeneration technique is developed that offers the low BER at low received using Xilinx KCU105 UltraScale FPGA for DPSK-NRZ signal. The designed technique consumes less power and provides the high-speed transmission for the designed optical regeneration system at more cost efficient in real time.

6. ACKNOWLEDGEMENT

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7. REFERENCES

[1] Kaminow I., Li T. and Willner A.E. Optical Fiber Telecommunications VB: Systems and Networks. 6th ed. United Sates of America: Academic press, 2013, pp. 95-300.

[2] Shake I. Takara H. and Kawanishi S. Technology for flexibly monitoring optical signal quality in optical communications. NTT Technical Review., 2004, 2(1), pp. 29-34.

[3] Pachnicke S. Fiber Optic Transmission Networks, Signals, and Communication Technology. 1st ed. Berlin Heidelberg: Springer, 2012, pp. 120-250.

[4] Hill K. Johnson D. Kawasaki B. and MacDonald R. CW three-wave mixing in single-mode optical fibers., 1978, 49(1)., J. Applied Physics, 1978, 49(1), 5098-5106.

[5] Imajuku W. Takada A. and Yamabayashi Y. Inline coherent optical amplifier with noise figure lower than 3 db quantum limit., Electron. Lett., 2000, 36(1), 63-64.

[6] Bogris A. Syvridis D. Kylemark P. and Andrekson P.A. Noise characteristics of dual-pump fiber optic parametric amplifiers., J. Lightw. Technol., 2005, 23, 2788-2795.

[7] Inoue K. Optical level equalisation based on gain saturation in fiber optical parametric amplifier., Electron. Lett., 2000, 36, 1016-1017.

[8] Matsumoto M. Regeneration of RZ-DPSK signals by fiber-based all-optical regenerators., IEEE Photonics Technol. Lett., 2005, 17, 1055-1057.

[9] Bres C.S. Wiberg A.O.J. Chavez-Boggio J.M. and Radic, S. Optical demultiplexing with extinction ratio enhancement based on higher order parametric interaction., 2009, In Proc. 35th IEEE- ECOC, 1-2.

[10] Zheng Z. An L. Li Z. Zhao X. and Liu X. All-optical regeneration of DQPSK/QPSK signals based on phase-sensitive amplification., Optics Communications, 2008, 281, 2755-2759.

[11] Tucker R.S. Green optical communications part ii: energy limitations in networks., IEEE J. Sel. Topics. Quantum Electron, 2011, 17, 261-274.

[12] Das B. Abdullah M.F.L. Shah N. All Optical Signal Restoration for 10G DPSK System," in Advanced Computer and Communication Engineering Technology, 1st ed., Vol. 315. H. A. Sulaiman, M. A. Othman, M. F. I. Othman, Y. A. Rahim, and N. C. Pee, Eds. Switzerland: Springer International Publishing, pp. 545-556, 2016.

[13] Avago Technologies. Altera® Optical FPGA Technology with MicroPOD™ Optics. United States of America (USA): Trade Brochure, 2015.

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