High Speed and Ultra Dense wavelength division multiplexing based passive optical network

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***Abstract :** Wavelength division multiplexing is a promising candidate for future passive optical networks ascribed to ultra high capacity and pacy systems that can be accomplished with compact, light weight and lower power consumption optical equipments. This research article explores the performance enhancement of 4 x 20 Gb/s WDM-PON system incorporating polarization diversity. The high speed system is attained to fulfill the wide bandwidth requirements of data services in PON by employing WDM system at channel spacing of 25 GHz. In order to suppress the polarization crosstalk and nonlinearities among adjacent channels of WDM, a polarization interleaving technique is included in the system.*

IndexTerms - WDM, PON, PI, OLT, ONU.

I. INTRODUCTION

The deployment of the time delay or time division multiplexing has been reported for passive optical networks to cater the wide bandwidth requirements of internet services [1]. But, the time division causes the issue of bandwidth sharing and consequently led to wastage of time as well as cost. On contrary, wavelength division multiplexing is a prominent and potential technology to overcome these limitations [2]. For FTTH services, WDM-PON is considered as the ultimate solution to offer wide bandwidth and fast communication. Bidirectional or full duplex passive optical networks are needed to cater the ever increasing demands of bandwidth hungry services [3]. However, bidirectional WDM PON networks suffers from a serious issue of crosstalk between downstream and upstream channels [4]. Polarization crosstalk is also an important performance degrading issue that needs to be resolved. Different approaches were made to suppress polarization crosstalk and inter-channel crosstalk such as combined WDM and TDM technology, multiple modulators, hybrid modulations etc [5]. However, these approaches are complex and do not supports high speed. At present, use of the NRZ is popular due to simple generation. But, in near future, advanced modulations such as DQPSK and DPSK are needed due to their high spectral efficiency and has power to combat with dispersions effects [6]. Moreover, wavelength reuse is an important factor to consider in passive optical networks to design a low cost WDM bidirectional system. Many research articles are reported so far to incorporate wavelength reuse. In this work, we are proposing the simple solution to suppress the channel crosstalk due to polarization and intra-channel crosstalk.

II. SYSTEM SETUP

For the accomplishment of proposed architecture a leading and compendious simulation tool that facilitates users to implement, investigate, and simulate communication system in optical domain, Optiwave's OptiSystem^{TM} is used. Figure 1 depicts the proposed WDM passive optical network at 20 Gbps employing differential quadrature phase shift keying (DQPSK) in downstream and non return to zero (NRZ) in upstream. Novelty of the system is use of polarization interleaving in WDM PON to combat with the polarization and inter-channel crosstalk. System proposed is symmetrical and also centralized lightwave that supports 8 WDM channels in this work. Internal structure of DQPSK is shown in Figure 2 (a) and decoder in Figure 2 (b). A laser light wave source at 193.1 THz frequency and 0 dBm input power is used. A polarization of even and odd channels is changed in order to analyze effects of nonlinear degradations on system. The linear polarizer transmits the linear polarization component that coincides with the transmission axis of the polarizer and eliminates the orthogonal component. Odd channels from λ_1- λ_3 carry same polarization and state of polarization (SOP) is fixed to 0 degree in linear polarizer. Even channels λ_2- λ_4 have the state of polarization orthogonal to odd channels i.e 90 degree. The investigated range for the proposed link is 40 Km. Eight WDM channels are modulated in central office with DQPSK modulation. From this point, downstream communication in bidirectional passive optical network initiates. The modulated DQPSK WDM signals are accumulated with the multiplexer of two 4 x 1, as well as the multiplexed signal is transmitted over 40-km SMF-28 (single-mode fiber).

In DQPSK, A pseudo random bit sequence generator is used to provide binary bit streams. Binary data is provided to 4-DPSK pre-coder and is performed for coding followed by two NRZ line-coders for pulse shape. Mach zhendar modulator 1, 2 are placed to modulate data into optical light signal. Then a sine generator with 1/4 the frequency of bit rate is modulated the data to provide different shifts to adjacent bits. through coupler and split the signal half-half and one signal is given to PD and another to time delay + phase delay. Signal detected and passed though regenerator and eye diagram analyzer. After transmission of 40 km, signal is de-multiplexed by 1 x 4 wavelengths with frequency spacing of 25 GHz. Receiver section consisting of optical couplers with coupling ration of 50:50 and divide signal for two pairs of photo-detectors that receives drive with time delay and phase shift to input signal. A p-i-n photodetector with 100% responsivity and 10 nA dark current is placed in the receiver by considering shot, thermal and ASE (Amplifier spontaneous noise) distortions. Electrical bias is provided to electrically subtracted output of balanced photodetectors followed by 3-R regenerator. A 3-R regenerator employed for re-sampling, re-shaping and re-amplification of the received data. Bit error rate analyzer is decision making component which calculate the final received quality factor, bit error rate (BER), signal to noise ratio (SNR) etc of the received signals. One half of downstream DQPSK signal is demodulated and other half is provided to the re-modulation. Reflective amplifier is modulated the data of NRZ signal over four frequency channels and multiplexed to travel for upstream. After 40 km transmission, signal is de-multiplexed and detected through PIN photo-diode followed by low pass filter and Eye diagram analyzer.

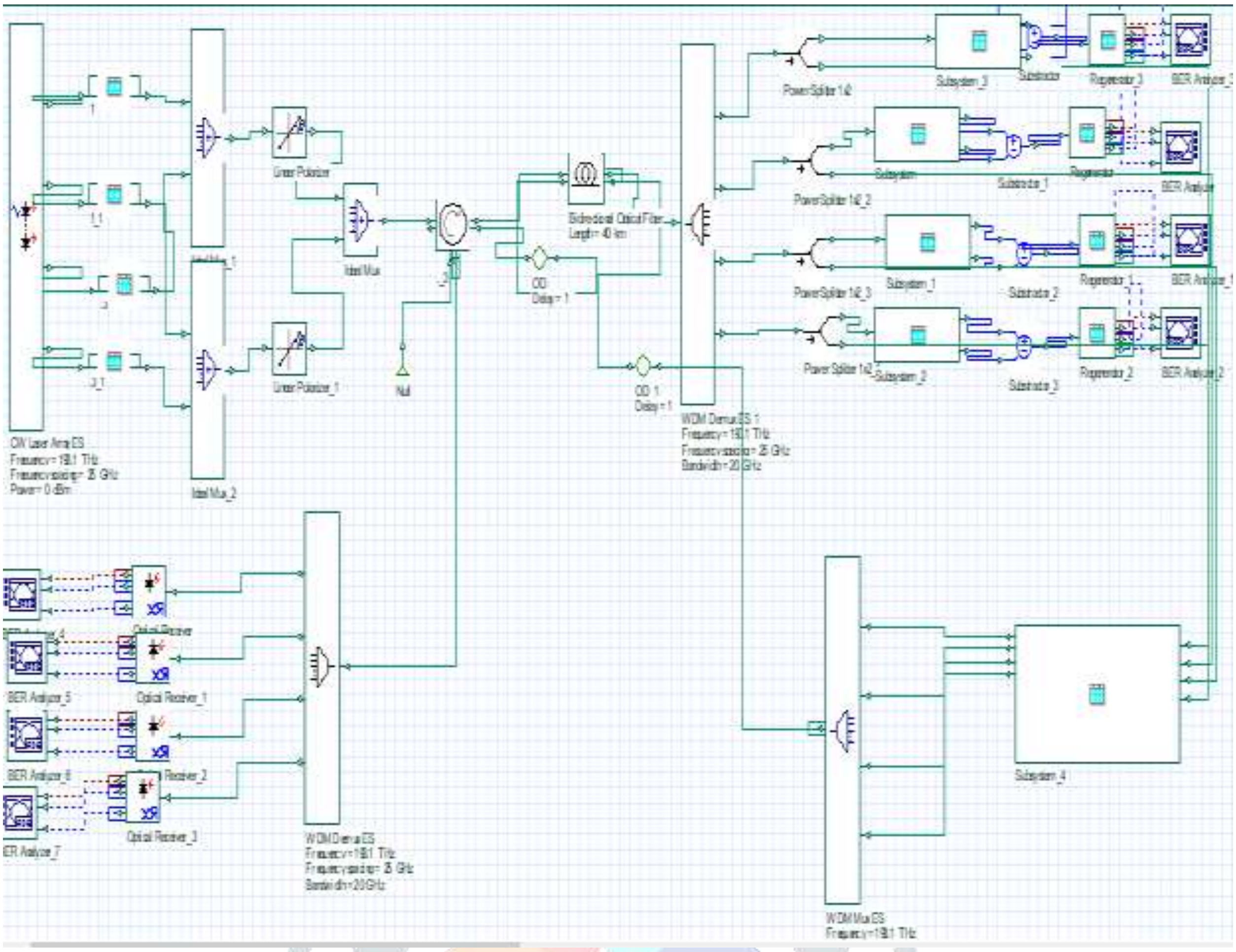
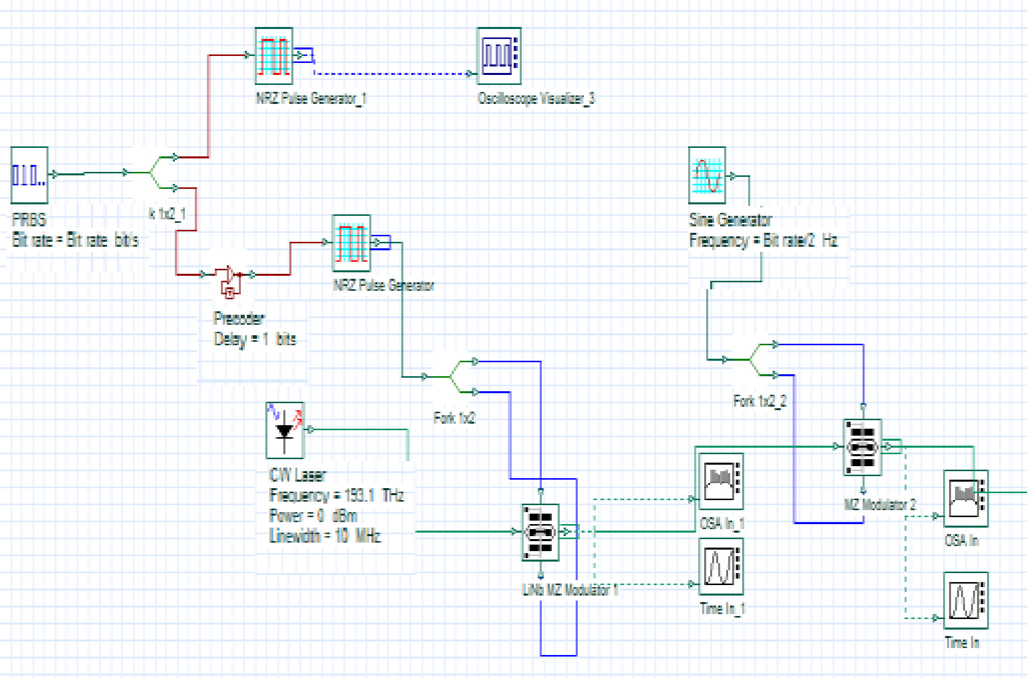
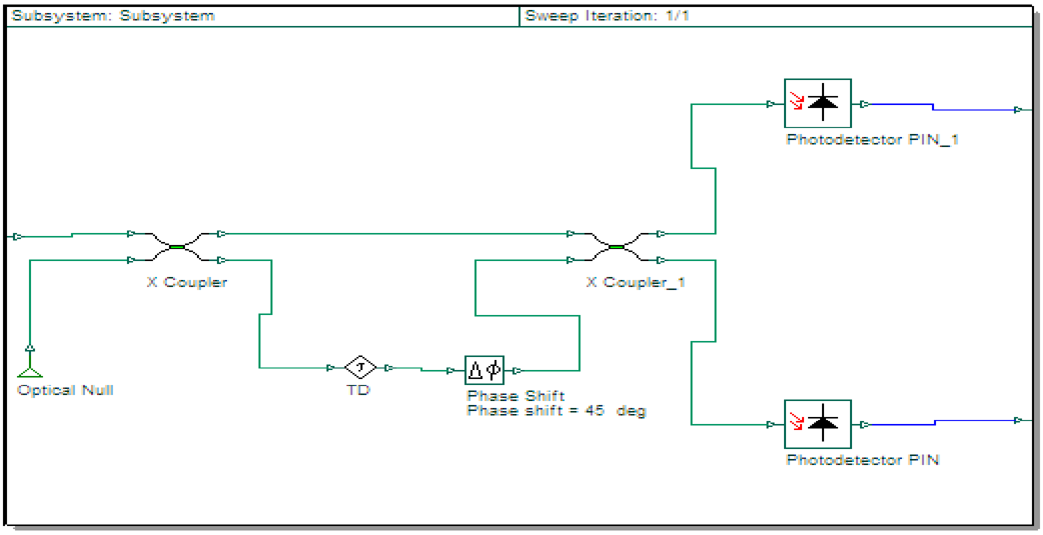


Figure 1 Proposed polarization interleaved WDM-PON



(a)



(b)

Figure 2 The internal structure of for (a) DQPSK transmitter (b) DQPSK decoder

III. RESULTS AND DISCUSSIONS

In order to design a polarization crosstalk suppressed systems, a passive optical network employing polarization interleaving is proposed. First and foremost, the investigation of proposed system has been done by taking different distances into consideration.

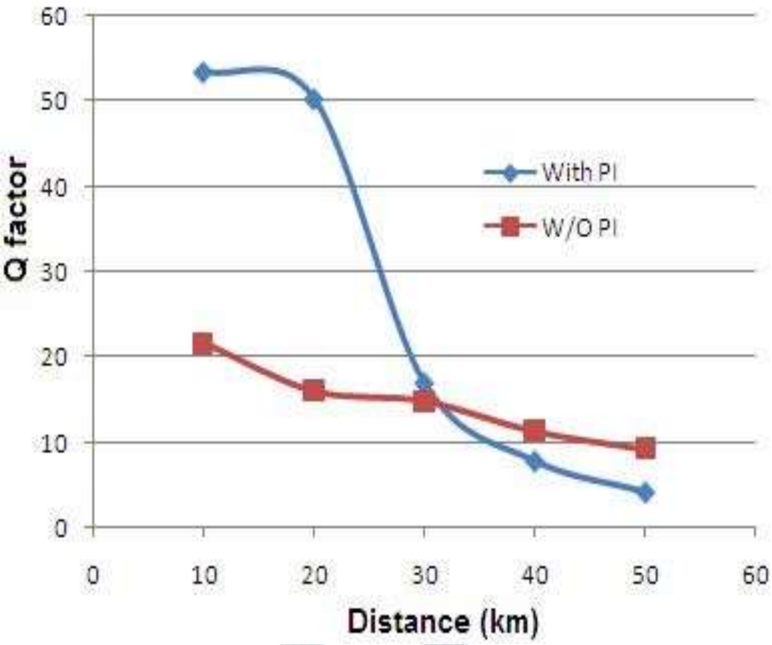


Figure 3 Graphical representation of Q factor with respect to different distances

Loop length is varied from 10 km to 50 km with the gaps of 10 km. To evaluate the results, Q factor is noted from Eye diagram analyzer. Figure 3 represents the graphical representation of Q factor versus distance for with and without polarization interleaving in WDM-PON. It is reported that with the increase in the link length, there is significant reduction in Q factor of the signal. Also, two different scenarios are proposed by considering the polarization interleaving and without polarization interleaving.

Table 1 Values of Q factor with respect to distance

Distance	With PI	W/O PI
10	55.75	21.59
20	46.59	16
30	18.22	14.84
40	8.04	11.33
50	4.22	9.26

Q factor decreases due to numerous factors such as the attenuation, pulse broadening, crosstalk among different channels etc. However, in this work, we accentuated on polarization crosstalk that emerges in multi-channel WDM systems and plays a vital role in signal degradation. It is evident from the investigation that because of the different states of polarization in even and odd channels of the proposed system, Q factor is obtained better than without polarization interleaved system. This is due to the fact that different states of polarizations minimize the interaction of signals between different wavelengths. This phenomenon led to a significant enhancement in Q factor and it is seen that when polarization interleaving is eliminated, Q factor decrease sharply and valid for 45 km distance as compared to with polarization interleaved system as given in Table 2.

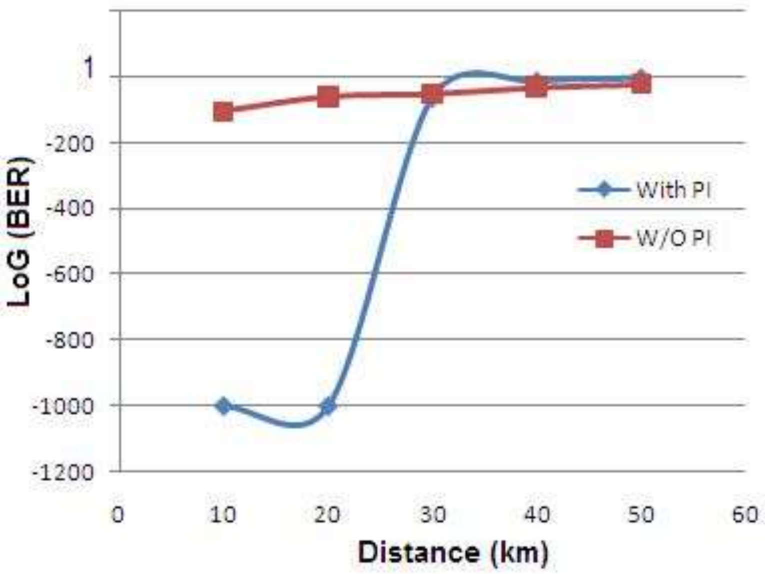


Figure 4 Graphical representation of LoG (BER) versus distance for proposed WDM PON

Figure 4 represents the LoG (BER) values when link length is varied from 10 km to 50 km. It is evident that as distance prolongs, there is increase in bit errors. Bit error rate is an important measure to evaluate the system performance. In proposed system that incorporates polarization interleaving, exhibits less errors as compared to without interleaved WDM passive optical network. Differential quadrature phase shift is employed in the system to suppress the crosstalk between upstream and downstream channels. However, DQPSK has done another task of inter symbol interference suppression due to four different phases. Other problem is also exists that is the inter channel interference in WDM PON. By employing polarization interleaving, we also suppress this issue. LoG (BER) is more in without polarization interleaved system and thus polarization inter leaving is recommended to use for better results. Distance is considered for the evaluation of the systems in terms of Q factor and BER. However, the next study is on the effect of input power on the system performance. Results such as Q factor, LoG (BER) and signal to noise ratio are accessed for investigation. So, in the proposed WDM passive optical network, launched power is varied from the laser source from -10 dBm to 5 dBm with the difference of 5 dBm. Figure 5 depicts the variation of Q factor with the launched power for with and without polarization interleaved system.

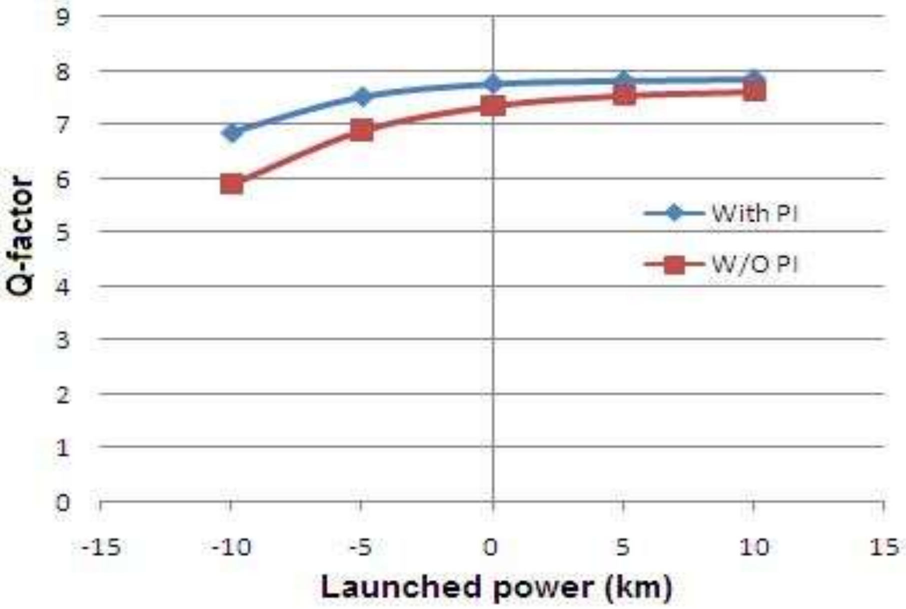


Figure 5 Representation of variation of Q factor with the launched power for with and without polarization interleaved system

Table 2 Values of Q factor versus launched power for with and w/o polarization interleaved system

Power	With PI	W/O PI
-10	6.85	5.89
-5	7.52	6.88
0	7.76	7.34

5	7.82	7.53
10	7.85	7.6

From the results as given in Table 2, it is observed that with the more power coupling into optical fiber, Q factor tens to increase. Increase in launched power serve as a power budget in the system. However it is also seen that high power input initiates the nonlinear effects due to the refractive index variations. But, in this setup power is limited to 5 dBm and this power level do not initiates the nonlinear effects. Thus, it is seen that WDM passive optical network with polarization interleaving provide better Q factor than without polarization interleaving. Figure 6 represents the LoG (BER) versus launched power in the system. It is observed that power increase, improves the BER and provide less BER for high powers that are launched in optical fiber. Bit error rate is more in the case of simple WDM passive optical network without incorporation of polarization interleaving.

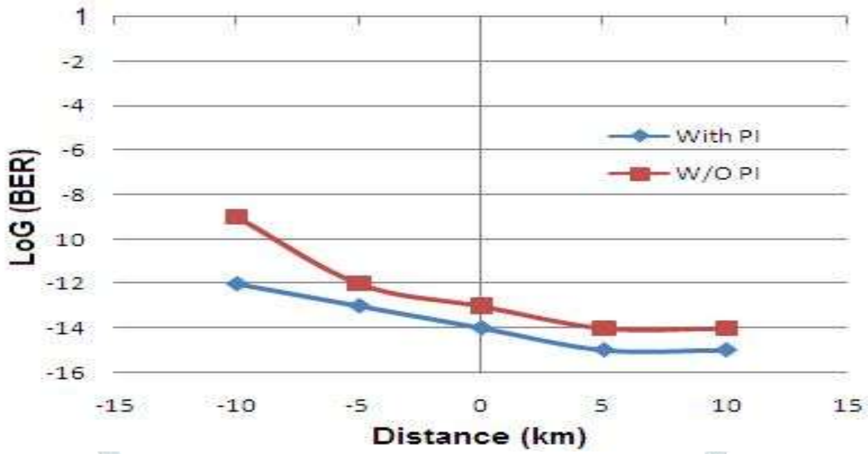


Figure 6 LoG (BER) versus launched power

Figure 7 depicts the performance of system for different launched powers in terms of signal to noise ratio. Signal to noise ratio is the measure of received signal power to noise. SNR should be maximum for better Q factors and less BER. It is evident from the Table 3 that signal to noise ratio increase with the enhancement in lunched power levels. SNR is obtained more in the polarization interleaved system till the launched power level of 0 dBm and less in case of the powers more than 0 dBm due to emergence of minor nonlinear effects. For without interleaving system, SNR is less till 0 dBm and increase further due to the effects of nonlinearity.

Table 3 Values of SNR at different power levels

Power	With PI	W/O PI
-10	27.06	23.94
-5	32.14	31.4
0	37.19	38.18
5	42 .22	44.36
10	47.23	50.1

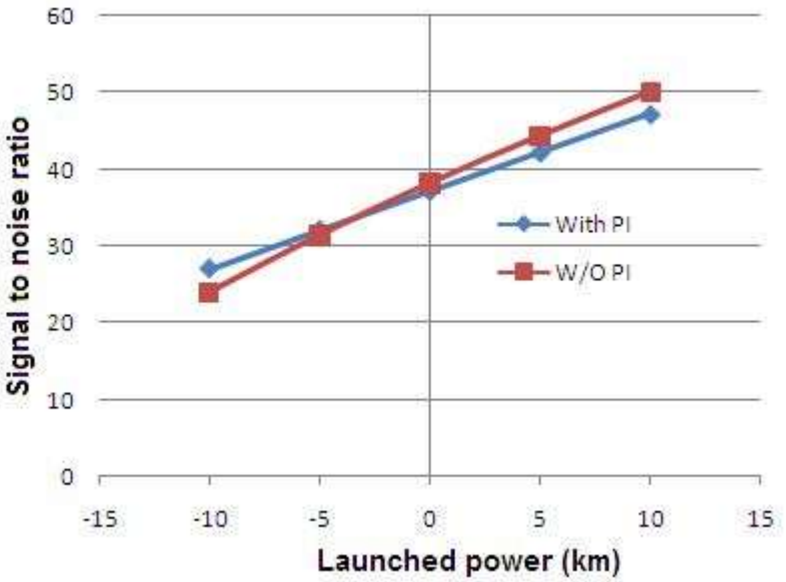
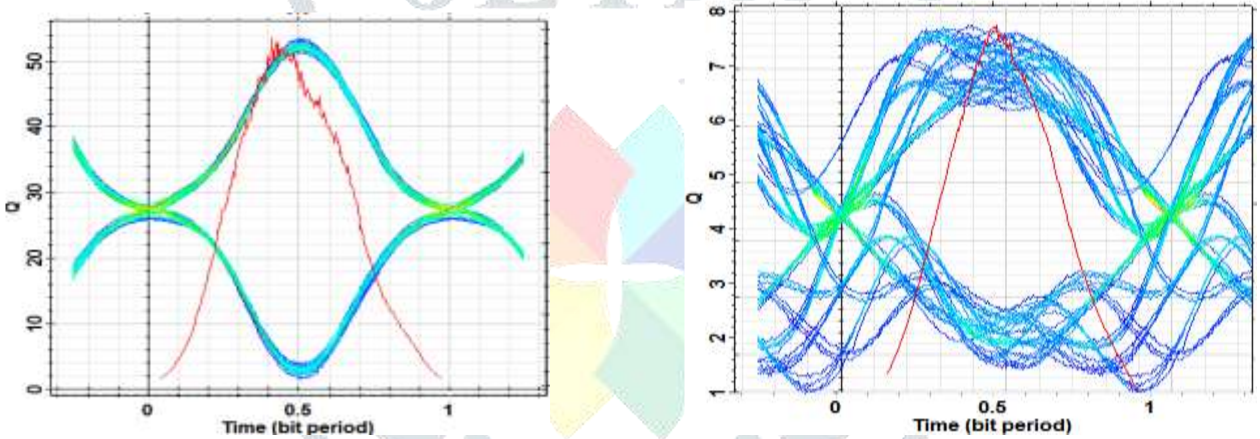


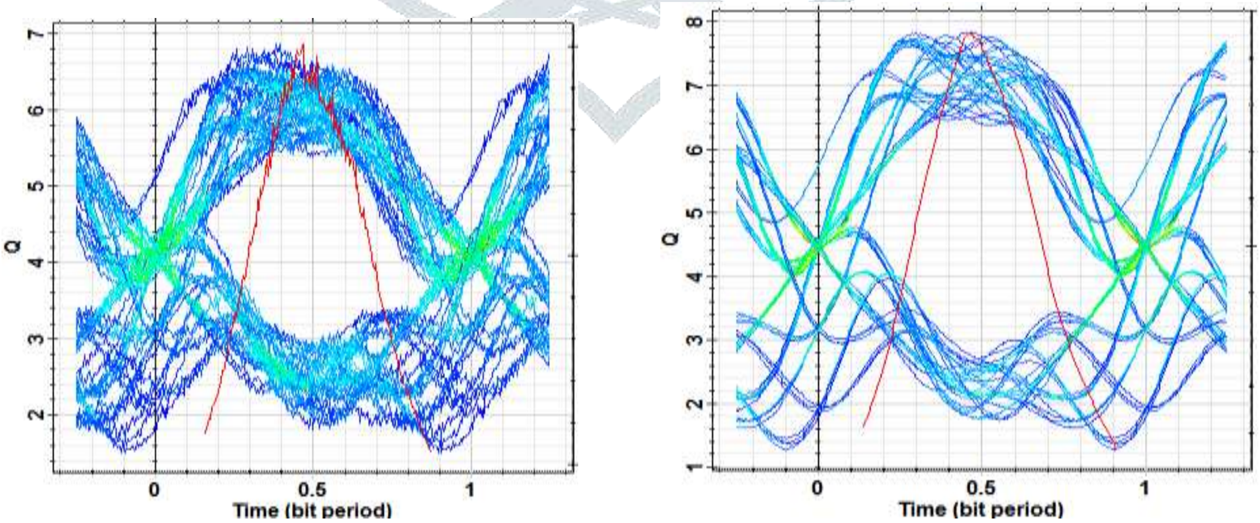
Figure 7 Signal to noise ratio of proposed system at 40 km for different levels of launched powers

Eye diagram of the system with and without polarization interleaving depicted in Figure 8 and Figure 9 for different link lengths, powers respectively. It is reported that Eye opening is more in case of 10 km link distance and closer increase with the increase in the distance. This is due to the fact that there significant attenuation, dispersion and nonlinear effects in the fiber optic. It is reported that at 10 km eye height is more as compared to 50 km and jitter is also less. More thickly the eye diagram appears more are the errors and less is the Q factor. Figure 8 (a) (b) represents the Eye diagram for the proposed system at 10 km and 40 km in case of polarization interleaved system.



(a) (b)

Figure 8 Eye diagrams for polarization interleaved WDM passive optical network at (a) 10 km and (b) 50 km



(a) (b)

Figure 9 Graphical representation of the system Eye diagrams for (a) -10 dBm and (b) 10 dBm

Also, Figure 9 depicts the performance of the polarization interleaved system at different launched power levels such that -10 dBm and 10 dBm. It is seen that the Eye opening is more in case of the 10 dBm and eye closer is more at low input power -10 dBm.

IV. CONCLUSION

This research explores the performance enhancement of 4 x 20 Gb/s WDM-PON system incorporating polarization diversity. The high speed system is attained to fulfill the wide bandwidth requirements of data services in PON by employing WDM system at channel spacing of 25 GHz. Results are compared in two different systems such that with and without polarization interleaved WDM-PON system. It is observed that WDM-PON with polarization interleaving cause fewer errors and provide enhanced performance as compared to without polarization system. At lower distances and less power levels, Q factor and SNR reported minimum and BER is more. Systems using DQPSK-NRZ and polarization interleaving works successfully for 50 km and polarization crosstalk, ISI effects are suppressed. Thus, this is an ultimate solution to WDM passive optical networks to support long distances as well as high data rate.

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