Comparative analysis of 40 Gbps Duo binary and VSB modulated data using second order PMD models on first order PMD compensator

GEETIKA, R. S. KALER, GURPREET KAUR*

Optical Fiber Communication Research laboratory (OFCR Lab), ECE Department, Thapar University, Patiala, 147004, Punjab, India

In this paper, the performance of 40 Gbps vestigial side band (VSB)/ Duo binary modulation with PMD models i.e. EMTY, Bruyere, and Planar sweep model has been investigated using deterministic PMD emulator module on first order PMD compensator. System performance is checked at different received optical power for various differential group delay (DGD). It is observed that planar sweep with VSB shows better performance than other i.e EMTY and Bruyere model. We have achieve BER of $2.22e^{-23}$,$1.4e^{-22}$, and$1.4e^{-18}$ with VSB modulated data for planar sweep, Bruyere and EMTY model at DGD 15ps respectively. Second order Bruyere model also gives us good agreement in system. The proposed system shows that VSB have more tolerance to PMD effects as compared to duo binary modulated data.

(Received June 13, 2016; accepted October 10, 2017)

Keywords: Polarization mode dispersion, Differential group delay, Vestigial side band, Principal state of polarization

1. Introduction

Polarization mode dispersion is considered as a limiting factor for high speed and long link communication for bit rate of 40 GB/s and higher [1]. Due to random nature of PMD, it is difficult to eliminate, so can be minimized by the use of correct modulation scheme. PMD emulation is important because network designers have to test and verify new technologies in presence of PMD, especially for systems that cannot have PMD compensators The PMD emulator effects are important whether PMD compensators are present or not in system with characteristics i.e. desired statistics, repeatability and stability etc. [2]. Second-order PMD is an important issue for system performance and PMD emulators should not only include first order but the second order also [3]. Advanced modulation formats have attracted much attention in present years as effective way to increase communications transmission capacity with standard single-mode fiber links [4].

Optical modulation formats like duo binary [5-6], differential quadrature phase-shift keying [7], Single Sideband (SSB) [8] and VSB [9] are spectrum efficient that makes them more immune to dispersion. In vestigial side band, one side band is passed completely whereas vestige of other side band is retained making them bandwidth efficient whereas Duobinary modualtion uses less than R/2 Hz of bandwidth to transmit R bits/sec. Due to narrow spectrum, the signals are less prone to dispersion as compared to other modualtion schemes.

Nelson et al. [10] investigated the performance of 40 Gb/s NRZ polarizing multiplexing (PM) system in presence of first-order and showed that the with PM, sensitivity of PMD increases due to crosstalk. Liu et al. [11] analyzed that the PMD penalties depends on many factors i.e. modulation format and receiver characteristic and evaluated on-off keying (OOK), differential phase-shift keying (DPSK) and differential quadrature phase-shift keying (DQPSK) modulation formats by the Importance Sampling method.

Kaur et al. [12] suppress the nonlineartity and dispersion in optical link with the help of optical phase conjugator. Kaur et al. [13] estimate and migitate the effect of four wave mixing in solition link. Chongjin Xie et al. [14] compared performance of first, second and all-order PMD models for systems with and without first-order PMD compensation. Harjit singh et al. [15] evaluated performance of 40 Gb/s duobinary optical transmitter for different scattering section dispersion and polarization-mode dispersion coefficient of single mode fiber and observed that the variable scattering section dispersion improves performance of duobinary system as compared to fixed scattering section dispersion

Previously proposed work involves only study on effects of PMD second order models using NRZ modulation only. Also, PMD penalties using DPSK, DQPSK and OOK modulation format has been investigated. Alternative to these formats, vestigial side band, and duobinary modulation can also be used to study effects of second order PMD models

In this paper, we have investigated the performance of second order PMD models on first order PMD compensator using vestigial side band and duo binary modulation formats. After introduction, this paper has been organized as follows: Section II describes second order PMD models followed by section III describing simulation setup while Section IV describes the results and discussion and the conclusion is drawn in section V.

2. PMD models

PMD is linear electromagnetic wave propagation phenomena that occur in single mode fiber. These fibers support two modes of propagation distinguished by their polarization. Using the Principal State Model, PMD can be characterized by the PMD vector [13]:

$$\vec{\tau}=\Delta\tau.\hat{p} \quad (1)$$

Where $\Delta\tau$ indicates differential group delay and $\hat{p}$ is the unit vector along the direction of slow principal state of polarization (PSP) and are constants and independent of frequency.

The Second order PMD vector is defined as [16-18]:

$$\tau_{\omega=}\frac{\partial\tau}{\partial\omega}= \Delta\tau.\hat{p}_{\omega} + \Delta\tau_{\omega}.\hat{p} \quad (2)$$

The term $\Delta\tau.\hat{p}_{w}$ defines depolarization of PSP and $\Delta\tau_{\omega}.\hat{p}$ indicates polarization chromatic dispersion (PCD) (i.e. change in chromatic dispersion due to polarization).PMD can also be described by 2×2 jones matrix (U) [14]. Second order models are constructed by combining various realizable elements with unitary *U* matrix to match with first- and second-order PMD vectors of Model and fiber.

Various second order PMD models are

a) EMTY model:

The EMTY model with Jones matrix *U*, consists of two sections of different rotational power is [11]:

$$U=U_2U_1 = exp\left(-j\frac{\emptyset_2}{2}\hat{r}_2.\bar{\sigma}\right).exp\left(-j\frac{\emptyset_1}{2}\hat{r}_1.\bar{\sigma}\right) \quad (3)$$

Where $\emptyset_1 = \Delta\tau\Delta\omega$,$\hat{r}_{1=}\hat{p}$ and $\emptyset_2 = |\vec{\tau}_{\omega}|$ and$\Delta\omega^2/2$,$\hat{r}_2 = \vec{\tau}_{\omega}/|\vec{\tau}_{\omega}|$. Here U_1 *and* U_2 denotes jones matrix, and this model only includes PCD.

b) Bruyere model:

In Bruyere, second order model consist three elements in diagonal form of *U* in distinction to the diagonal model of first-order PMD and also uses frequency dependent matrices [11].

$$U = \begin{Bmatrix}\cos k\Delta\omega & -\sin k\Delta\omega\\ \sin k\Delta\omega & \cos k\Delta\omega\end{Bmatrix}\begin{Bmatrix}\exp(-\emptyset/2) & 0\\ 0 & \exp(-\emptyset/2)\end{Bmatrix}\begin{Bmatrix}\cos k\Delta\omega & \sin k\Delta\omega\\ -\sin k\Delta\omega & cosk\Delta\omega\end{Bmatrix} \quad (4)$$

Where $\emptyset = \Delta\tau\Delta\omega + \Delta\tau_{\omega}\Delta\omega^2/2$ and k=$|\hat{p}_{\omega}|/4$. This model includes both PSP depolarization and PCD.

c) Planar sweep model:

The planar sweep model emulates PSP depolarization producing vector that traces out a circle on the Poincare sphere with *Δω*. and minimizes higher orders of PMD [16].

$$U = \begin{pmatrix}\exp(-j\frac{\hat{p}_{\omega\Delta\omega}}{2} & 0\\ 0 & \exp(j\frac{\hat{p}_{\omega\Delta\omega}}{2}\end{pmatrix}\begin{pmatrix}\cos\frac{\Delta\tau_{1\Delta\omega}}{2}+j\frac{\hat{p}_w}{\Delta\tau_1}sin\frac{\Delta\tau_1\Delta\omega}{2} & -j\frac{\Delta\tau}{\Delta\tau_1}sin\frac{\Delta\tau_{1\Delta\omega}}{2}\\ -j\frac{\Delta\tau}{\Delta\tau_1}sin\frac{\Delta\tau_{1\Delta\omega}}{2} & cos\frac{\Delta\tau_{1\Delta\omega}}{2}-j\frac{\hat{p}_{\omega}}{\Delta\tau_1}sin\frac{\Delta\tau_1\Delta\omega}{2}\end{pmatrix} \quad (5)$$

Where, $\Delta\tau_{1=}\sqrt{\Delta\tau^2+\hat{p}_{\omega}{}^2}$includes only PSP depolarization.

3. Simulation setup

Fig. 1 shows the proposed simulation setup for PMD emulator. The transmitter consists of duobinary and vestigial side band modulator. The modulated signal is then passed through the PMD emulator which includes effect of Bruyere, planar sweep and EMTY models of second order PMD followed by attenuator. Here, deterministic emulator is used which produces particular DGD value at particular frequency. Then signal is passed through first order compensator to remove first order PMD completely for further study of second order PMD effects. After that received optical power, BER and eye diagrams are measured to study effects of PMD by using optical power meter, BER analyzer, and signal analyzer. The internal structure for Duo-binary and VSB is shown in Fig. 2. Fig. 2(a) shows the setup for duobinary modulation.

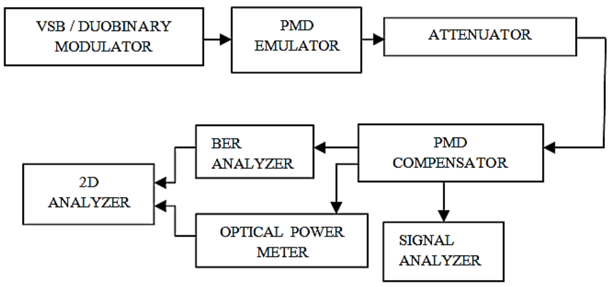
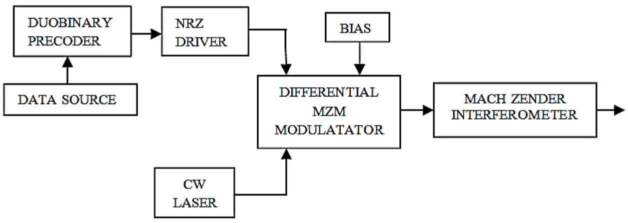
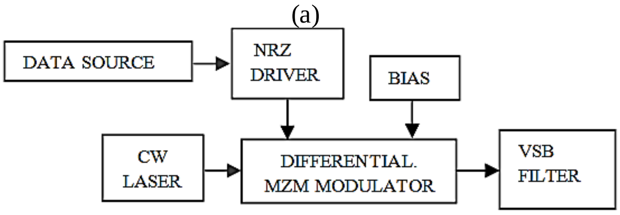


Fig. 1. Block diagram of proposed PMD emulator setup

The data source produces a PRBS at a bit rate of 40 Gbit/s which is then encoded by duo binary encoder consisting of 1 bit delay line. And the delay output is then added to original signal to produce zero mean three level signal. Then duobinary encoded data is converted into NRZ signal. After that signal passes through differential MZM modulator having extinction ratio 35 dB and biased at minimum transmission followed by Mach zender interferometer.



(a)



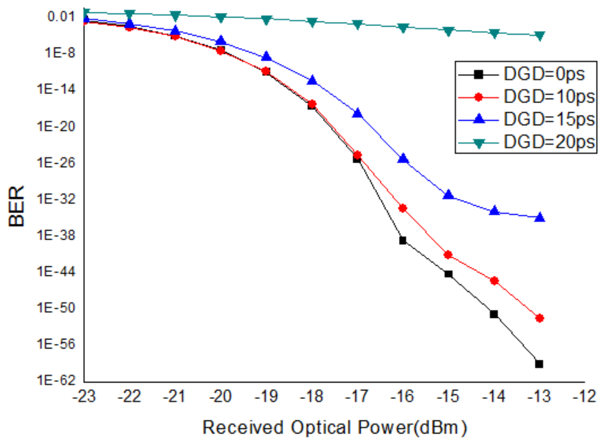
(b)

Fig. 2. Internal block diagram for: (a) Duobinay (b)VSB

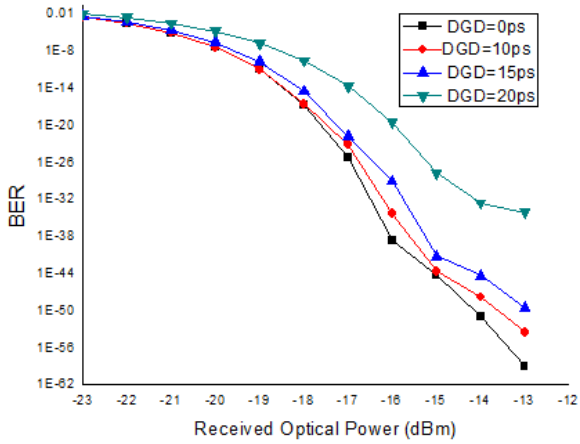
Fig. 2(b) shows the VSB modulation.In this, 40Gb/s data produced by data source is first modulated by using differential Mach zender modulator with 35 dB extinction ratio and is then passed through vestigial side band filter which is Gaussian band pass filter with 200Ghz bandwidth to remove unwanted frequencies.

4. Results and discussion

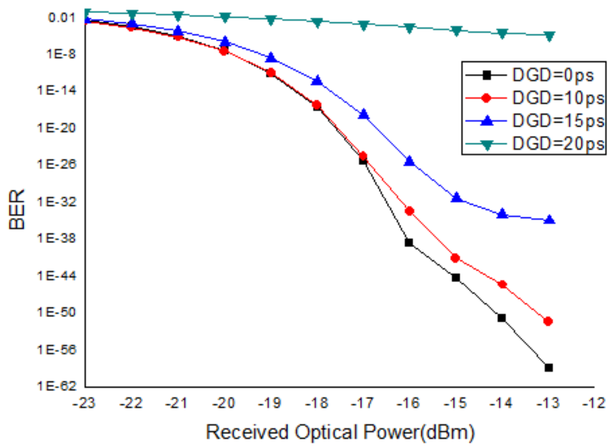
The proposed setup of PMD emulator is simulated using VPI transmission maker. Fig. 3 and 4 graphically shows the variation of BER against received optical power. The BER is measured for DGD values 0ps, 10ps, 15ps and 20 ps against received optical power having value from -23 dBm to -13dBm with step of 1 dbm for both modulations schemes using three models of second order PMD.



(a)

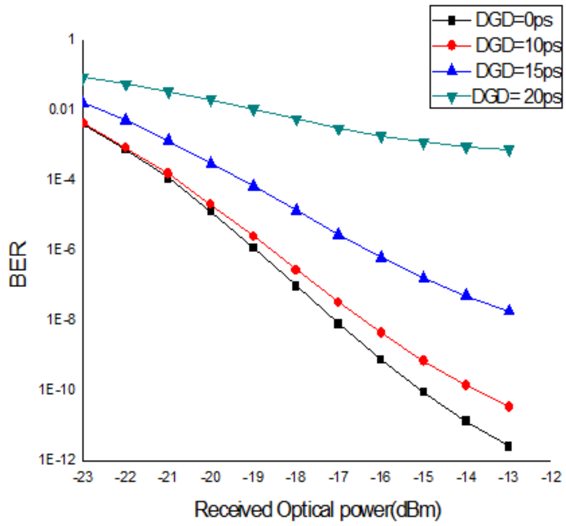


(b)

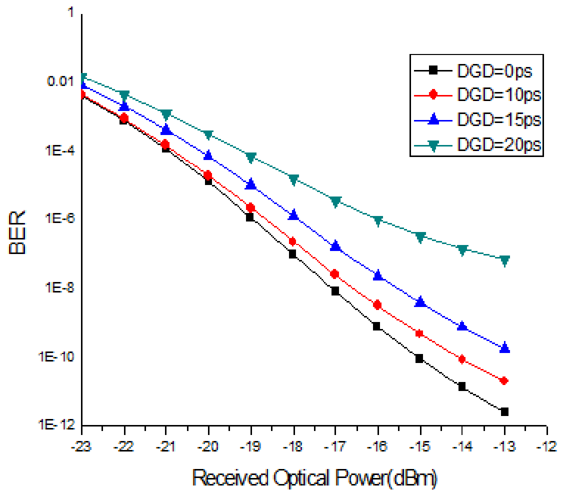


(c)

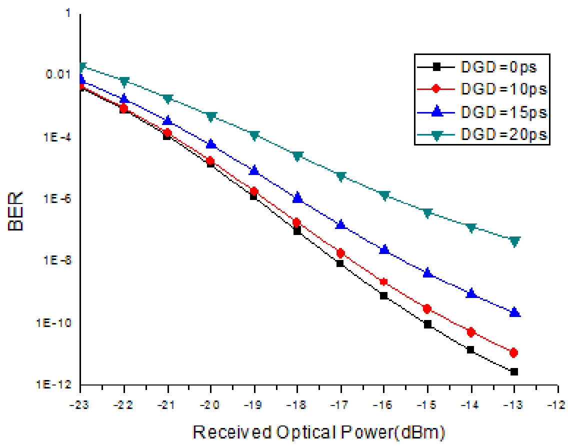
Fig. 3. Graphical representation for BER against Received optical power for VSB: (a) EMTY model (b) Bruyere model; and (c) Planar sweep model



(a)



(b)

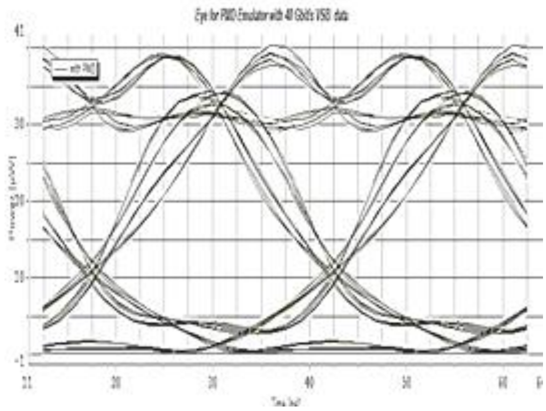


(c)

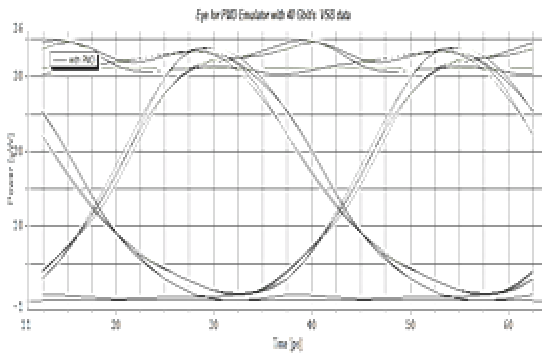
Fig. 4. Graphical representation for BER against Received optical power for Duo binary: (a) EMTY model (b) Bruyere model; and (c) Planar sweep model

From results, it is observed that three models of second order PMD shows less BER with VSB modulated data as compared to duobinary modulated data for all values of received optical power. It is also achieved that VSB with planar sweep model shows less second order effects in comparison with bruyere and EMTY model. For instance, BER value is 2.22e^{-23}, 1.4e^{-22}, and 1.4e^{-18} for planar sweep, bruyere, EMTY model with VSB modualted data at 15ps DGD for -17dBm received optical power respectiely and the BER value is 1.4e^{-18}, 1.44e^{-07} and 1.66e^{-07} for planar sweep, bruyere, EMTY model with duo-binary at 15 ps DGD for -17 dBm, respectiely. From all these, it can be concluded that VSB modualtion shows more tolerance to PMD effects due to bandwidth efficiency of VSB.

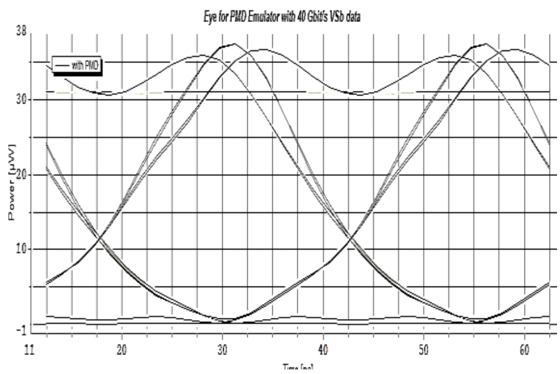
Fig. 5 and 6 shows the eye diagrams for VSB and duobinary modulated data using second order PMD models. An eye diagram shows the signal quality and fast advanced signal transmission.



(a)



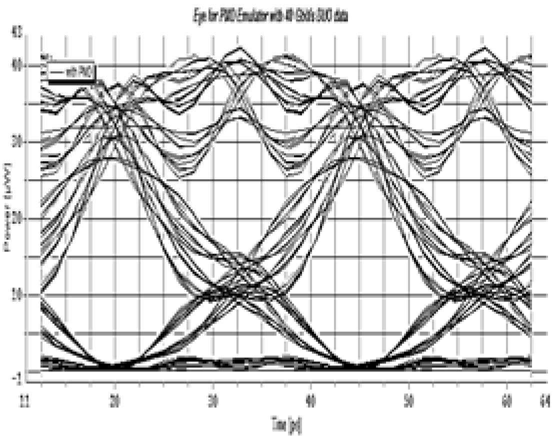
(b)



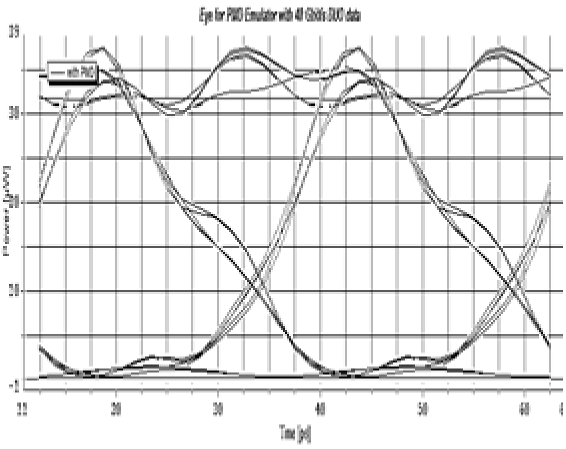
(c)

Fig. 5. Eye diagram with VSB for (a) EMTY model (b) Bruyere Model and (c) planar sweep Model

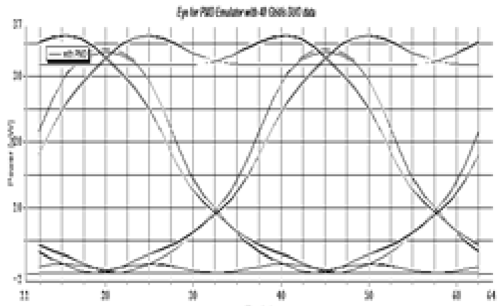
The closure of eye diagram represents distortion in the signal waveform due to noise and inters- symbol- interference. In this way, an open eye diagram corresponds to minimum signal distortion.



(a)



(b)



(c)

Fig. 6. Eye diagram with duobinary modulated data for (a) EMTY model (b) Bruyere Model and (c) planar sweep model

5. Conclusion

The investigation of PMD induced impairments with second order models for VSB and Duo binary modulated data using deterministic PMD emulator has been carried out. PMD emulation is important because network designers have to test and verify new technologies in presence of PMD, especially for systems that cannot have PMD compensators. From the results, we have concluded that planer sweep model for both cases (VSB and duobinary) shows better performance than other models. Further, we have also show that using VSB we have achieved better performance than duo binary. We have achieved BER ($2.22e^{-23}$, $1.4e^{-22}$, and $1.4e^{-18}$) with VSB modulated data for planar sweep, Bruyere and EMTY model at DGD 15ps, respectively. Second order Bruyere model also gives us good agreement in proposed system. The proposed system also shows that VSB have more tolerance to PMD effects as compared to duo binary.

References

[1] H. Sunnerud, M. Karlsson, C. Xie, P. A. Andrekson, J. Lightwave Technol. **20**, 2204 (2002).

[2] L. S. Yan, X. S. Yao, M. C. Hauer, A. E. Willner, J. Lightwave Technol. **24**(11), 3992 (2006).

[3] R. Khosravani, I. T. Lima Jr., P. Ebrahimi, E. Ibragimov, A. E. Willner, C. R. Menyuk, IEEE Photon. Technol. Lett. **13**, 127 (2001).

[4] M. Vanhoecke, A. Aimone, N. Argyris, S. Dris, R. Vaernewyck, K. Verheyen, M. Gruner, G. Fiol, D. Apostolopoulos, H. Avramopoulos, G. Torfs, J. Lightwave Technol. **35**(4), 862 (2016).

[5] K. Yonenaga, S. Kuwano, IEEE J. Lightwave Technol. **15**(8), 1530 (1997).

[6] Simranjit Singh, Elsevier: Optik **125**(21), 6527 (2014).

[7] R. Griffin, A. Carter, Proc. OFC, California, USA, paper WX6, pp. 367- 368, (2002).

[8] M. Sieben, J. Conradi, D. Dodds IEEE J. Lightwave Technol. **17**(10), 1742 (1999).

[9] Tiago G. Silveira, António, L. J. Teixeira, Ana P. S. Ferreira, Paulo M. N. P. Monteiro, IEEE Photonics Technology Letters **18**(21), (2006).

[10] L. E. Nelson, T. N. Nielsen, H. Kogelnik, IEEE Photon. Technol. Lett. **19**(13), 738 (2001).

[11] H. Liu, X. Zhang, K. Chen, Opt. Commun. **259**, 640 (2006).

[12] G. Kaur, M. S. Patterh, Elsevier: Optik- International Journal of Light and Electron **125**, (2014).

[13] G. Kaur, R. S. Kaler, Simranjit Singh, JETP Letters **105**(5), 279 (2017).

[14] X. Chongjin, L. Moller, Optical Fiber Communication Conference **3**, 3, OFC (2005).

[15] Harjit Singh, Anu Sheetal, Optik **123**, 1520 (2012).

[16] C. R. Menyuk, A. Galtarossa, Book: Springer, USA 70 (2005).

[17] M. Wegmuller, S. Demma, C. Vinegoni, N. Gisin, IEEE Photonics Technology Letters **14**(5), 2002.

[18] G. Kaur, R. S. Kaler, N. Kwatra, Optoelectron. Adv. Mat. **9**(9-10), 1110 (2015).

*Corresponding author:gksumman@gmail.com