Coherent Optical OFDM System or Long-Haul Transmission

Simarjit Singh Saini
Department of Electronics and Communication Engineering, Guru Nanak Dev University,
Regional Campus, Gurdaspur, Punjab, India

Anu Sheetal
Department of Electronics and Communication Engineering, Guru Nanak Dev University,
Regional Campus, Gurdaspur, Punjab, India

Harjit Singh
Department of Electronics and Communication Engineering, Guru Nanak Dev University,
Regional Campus, Gurdaspur, Punjab, India

Abstract- In this paper, the coherent optical – orthogonal frequency division modulation (CO-OFDM) technique for transmission of optical signal at 10Gbps data rate has been investigated. The CO-OFDM technique has been evaluated using quadrature phase shift keying (QPSK) modulation technique. The use of Dispersion compensation fiber (DCF) in various compensation schemes, i.e., post, pre and symmetrical configuration along with Single mode fiber (SMF) has been studied. The effect of variation in input power values and various compensation schemes has been investigated in terms of Q-factor, bit error rate (BER). Q-factor has been calculated from the constellation diagram. The overall observation shows that the faithful transmission distance can be increased by using DCF and the better performance is observed in using DCF in post compensation scheme in QPSK when the input laser power is 5dBm. It is determined that faithful transmission without using compensation scheme is possible for 100km. As we shift above 100km compensation scheme are required for realistic transmission and the best choice is post compensation scheme for transmission up to 145km.

KEYWORDS: QAM, QPSK, DCF, SMF, CO-OFDM

I. INTRODUCTION

The internet traffic growth demands increased bandwidth and high data rate. According to Cisco Visual networking index, the internet traffic from 2009 to 2014 will fourfold. The wide range of online application will lead to increase in the bandwidth demand in the future. The spectral efficiency, which is the information capacity per unit bandwidth is one of the important merit figure in optical communication. Intensity modulation and direct detection are basically used in optical networks, but spectral efficiency obtained is very less. Recently, many advanced modulation formats in signal amplitude, phase, and polarization has been investigated to increase the capacity of the system. Coherent detection when combined with the advance modulation technique can easily reach the spectral efficiency of several bits/s/Hz. One of these techniques is the optical OFDM. The concept of OFDM was first discovered at Bell labs in 1966 as a substitute for the frequency division multiplexing (FDM) technique.

In 1980, Peled and Ruiz [1] studied the cyclic prefix to mitigate the effect of the inter symbol interference (ISI). Cyclic prefix is a repetition of the last part of an OFDM symbol to the beginning of that symbol which will help to eliminate the ISI and allow channel estimation and equalization. In the year 1996, Pan and Green [2] studied the use OFDM technique in an optical communication system. The main advantage of the OFDM is its ability to overcome optical channel dispersion. In year 2001, Dixon et al. [3]introduced the use of OFDM in optical communications to compensate the dispersion in multimode fiber (MMF), when they revealed that the multipath fading in wireless was similar to that in an MMF channel. In 2008 modified version of OFDM was proposed by Weinstein and Ebert [4] where the discrete Fourier transform (DFT) was used instead of the sinusoidal modulators. This reduced the OFDM design complexity. In year 2011, Arthur James Lowery, Liang B. Du, [5] proposed optical OFDM for dispersion compensation in long-haul optical communications systems.

In the year 2013, Hui Wang, Deming Kong[6] proposed performance evaluation of differential APSK modulated coherent optical OFDM system. Performance of amplitude and phase shift keying (APSK) modulated CO-OFDM with and without differential encoding was investigated. In the year 2013, Khaled Alatawi et. al., [7] investigated the architecture of 1Tbits/s Wavelength Division Multiplexing (WDM) system by using a Coherent Optical Orthogonal Frequency Division Multiplexing (CO-OFDM) with 4-QAM for long haul transmissions of 1800km SMF. In the year 2014, Anu Sheetal et. al., [8] analyzed Of 10Gbps CO-OFDM based optical communication system and investigated that effect of noise is negligible upto 60km of transmission distance.

Up till now the research for CO-OFDM using SMF with 4-QAM technique is available. In this work CO-OFDM using DCF along with SMF is analyzed with 4 QPSK technique. Various dispersion compensation schemes have been studied on the basis of Q-factor which is calculated from the constellation diagram for transmission distance ranging from 20-150km at constant input power. In section II, Q-factor and BER estimation for CO-OFDM is explained Section III gives the system description of CO-OFDM system, in section IV results has been discussed and at last in section V. Conclusions are made.

II. Q-FACTOR AND BER ESTIMATION BY EB/N_0 FOR CO-OFDM

Gauss distribution quality (E_b/N_o) is used for BER estimation in a digital communication system.
E_b/N_o is presented as:

$$\frac{E_b}{N_o} = \frac{E_b}{N_0/2} \qquad \text{(i)}$$

where E_b is the average energy per bit, i.e. the ratio of signal power to the duration of each bit. N_o is the noise power spectral density, ie., the ratio of noise power and the noise bandwidth. Normally for quickly accessing the signal quality eye diagram is preferred [9]. The eye opening can be used to measure the signal quality and shows bandwidth and noise limitations. For OFDM system the received eye obtained by overlapping subsequent OFDM system reveals little distribution of the signal levels. This is because the signal is a superposition of sinusoids at the subcarrier frequencies, and each sinusoid is phase modulated. Thus, no particular peaks or openings can be discerned. The constellation, obtained just before the threshold in the OFDM receiver, is thus used to assess signal quality. For CO-OFDM systems with QPSK mapping, the constellation of received digital data of all subcarriers shows four clusters of data points corresponding to four QPSK information symbols and the noise sources that spread each information symbol are mainly amplified spontaneous noise (ASE), phase noise of laser, chromatic dispersion, and fiber nonlinearity. In the system. [9]. Since in optical OFDM, nonlinear distortions are approximate to Gaussian distribution, besides, ASE and phase noise of laser can also be regarded as Gaussian noise, therefore, the BER can be derived from the symbol variance [10]. Assuming there is no crosstalk or interference between two orthogonal carriers, the q can be obtained as

$$q = \sqrt{\frac{E_b}{N_o}} = \sqrt{\frac{E_b}{N_o}} = \frac{\mu}{\sigma} = \frac{\mu_y}{\sigma_y} \qquad \text{(ii)}$$

Where μ and σ represent the mean and standard deviation of one constellation point of all OFDM subcarriers data respectively and they can obtain as μ_y and σ_y, where y stands for the considered branch (I or Q) [4]. In order to improve the estimation number of sample points, all symbols are translated into a single quadrant.

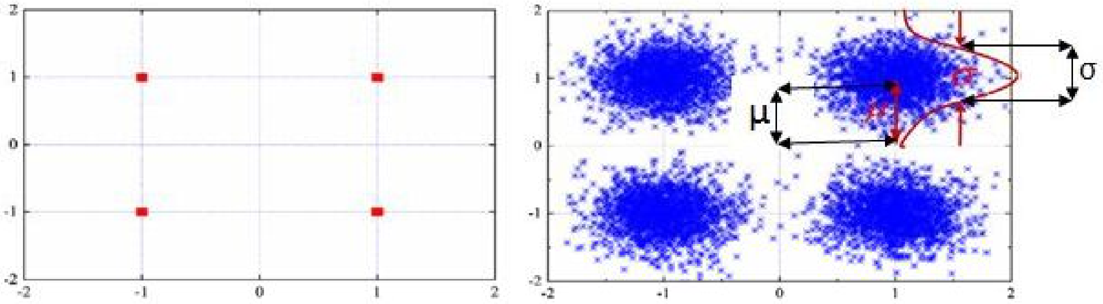


Figure.1Input and output constellation diagram

Then Q factor and BER is obtained as:

$$Q = 10\log_{10} q^2 \qquad \text{(iii)}$$

And

$$BER = Q\left(\sqrt{\frac{Eb}{N_0/2}}\right) = \frac{1}{2}\,erfc\left(\sqrt{\frac{E_b}{N_0}}\right) = \frac{1}{2}\,erfc\left(\frac{q}{\sqrt{2}}\right) \qquad \text{(iv)}$$

by this method when we calculate the value of mean μ and the standard deviation σ from the I or Q branch of one quadrant of the constellations then the value of q can be obtained from eq.(ii). Finally the value of Q and BER can be calculated by using eq. (iii) and (iv). The theoretical foundation of this method is that all impairments are regarded as Gaussian noise in CO-OFDM.

III. SYSTEM DESCRIPTION

The system for CO-OFDM for long haul transmission in both configurations (without DCF and with DCF) is shown in figure.2. Case 1 is followed when only SMF is used and Case 2 is followed when DCF is considered along with SMF.

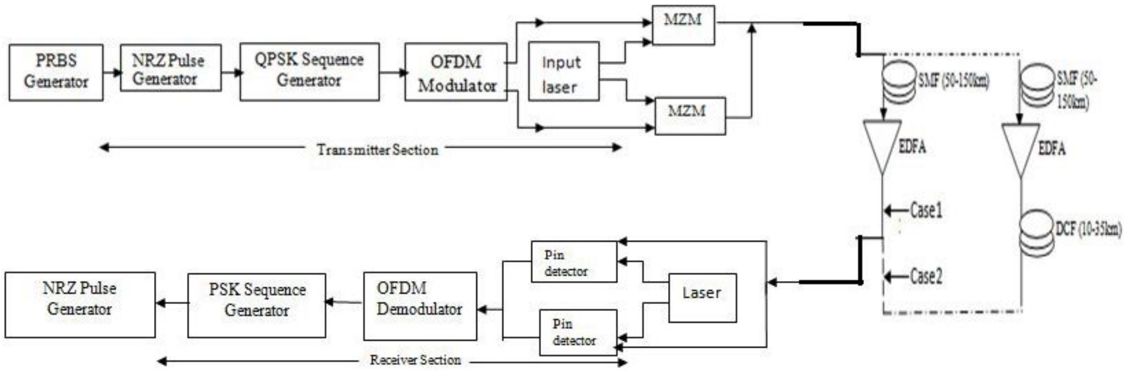


Figure. 2 simulation setup of CO-OFDM model

The system mainly consist CO-OFDM transmitter, optical fiber transmission link and CO-OFDM receiver as shown in Figure.2. In the transmitter end consists the PRBS Generator generate the pseudo-random binary sequence and 4-

QPSK (2-bit symbol) Sequence generator. The 4-QPSK Sequence is connected to an OFDM modulator with a 512 subcarrier and 1024 FFT points. The in-phase (I) and quadrature (Q) of the resulting signal from the OFDM modulator is transmitted to the direct I/Q optical modulator which consists of two lithium Niobate (LiNb) Mach-Zehnder modulators (MZM). The electrical signal from the OFDM modulator will be modulated by MZM to the optical carrier with a laser source of 193.05 THz. The input laser power is 5dBm. The resulting optical signal is then transmitted through the SMF with a dispersion of 16 ps/nm/km, a dispersion slope of 0.08 ps/nm^2/km, an attenuation of 0.2 dBm/km and a nonlinearity coefficient of 2.6×10^{-20}. An Erbium Doped Fiber Amplifier (EDFA) is used to boost up the signal and to compensate the losses during transmission [11].
In case 2 the pre, post and symmetrical compensation techniques are analyzed. In pre compensation scheme first the DCF is used and then the SMF is attached and the signal is transmitted over this transmission link. In post compensation scheme first the SMF is used and then the DCF is used to compensate the dispersion caused during the transmission of signal. Similarly in symmetrical compensation scheme first the DCF is used then SMF and then the DCF again.

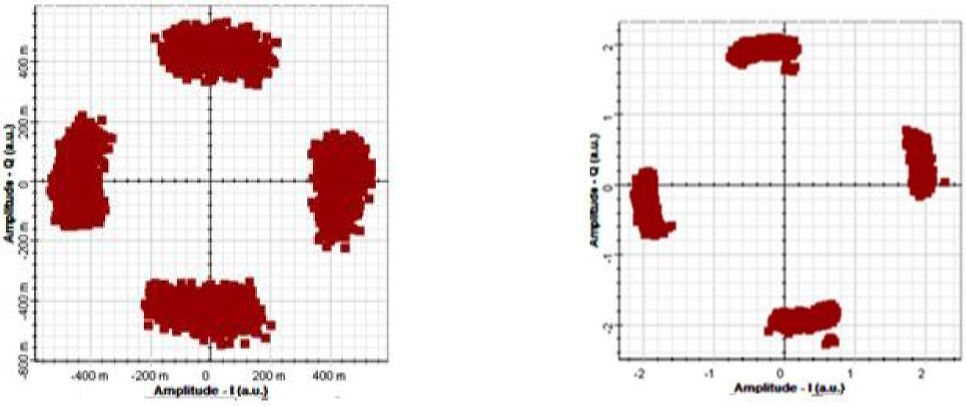
IV. RESULTS AND DISCUSSIONS

Case I. Effect of compensation schemes

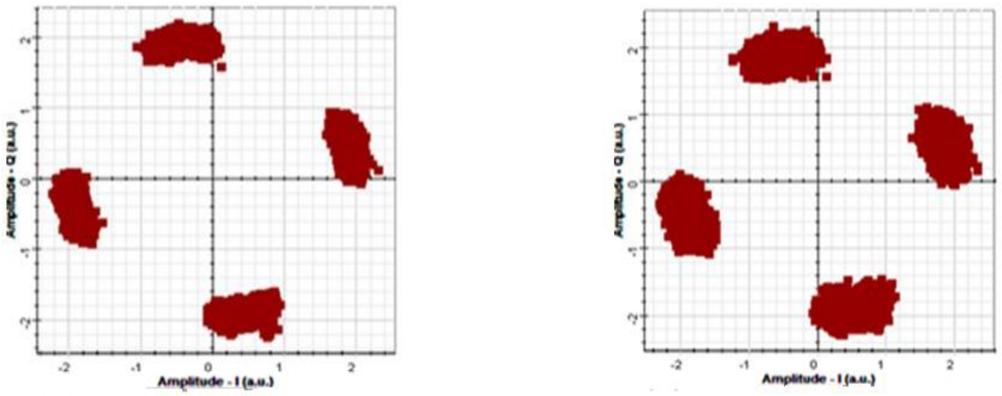
The performance of CO-OFDM system using QPSK modulation technique is analyzed for transmission distance varying from (50-150km). Q-factor and the BER are inversely proportional to each other as the Q-factor increases the BER value decreases. The use of DCF in pre, post and symmetrical compensation are investigated. With the increase in the transmission distance dispersion of optical signal starts dominating, therefore it compensates DCF [12]. For the use of DCF along with the SMF the product of the dispersion and length of fiber must be equal.

Table 2
Parameter of SMF and DCF

	Length	Dispersion	Dispersion Slope	PMD Coefficient	Attenuation
SMF	100km	16 ps/nm/km	0.08ps/nm^2/km	0.2 ps/km	0.2 dB/km
DCF	25 km	-64 ps/nm/km	-0.32ps/nm^2/km	0.2 ps/km	0.2 dB/km



(a) **(b)**



(c) (d)

Figure.3 Showing a constellation diagrams after at input power 5dBm. (a) Without DCF (b) With DCF in post compensation (c) With DCF in symmetrical compensation (d) With DCF in pre compensation.

The constellation diagrams as shown in Figure.3 are used to analyze the effect of variation of the transmitted signal in various DCF compensation when the input power is 5dBm and bit rate is 10Gbps. From these diagrams it is observed that signal transmission of DCF along with SMF as the distortion decreases. These constellation diagrams also used for the calculation of Q-factor as mentioned with the use of DCF.

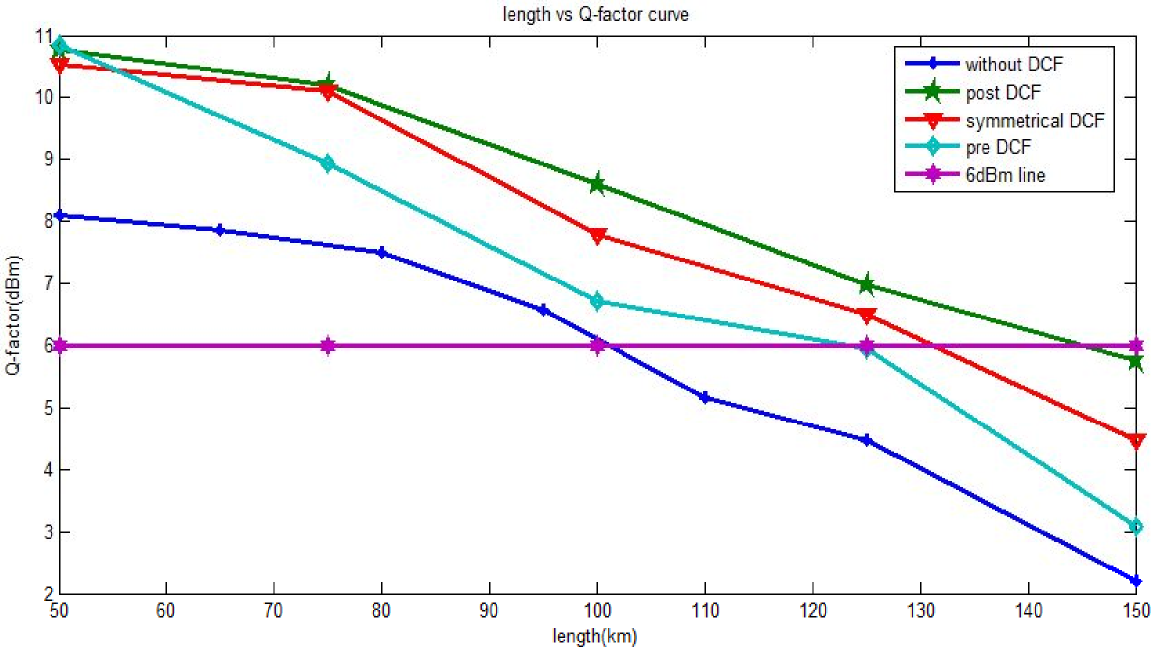
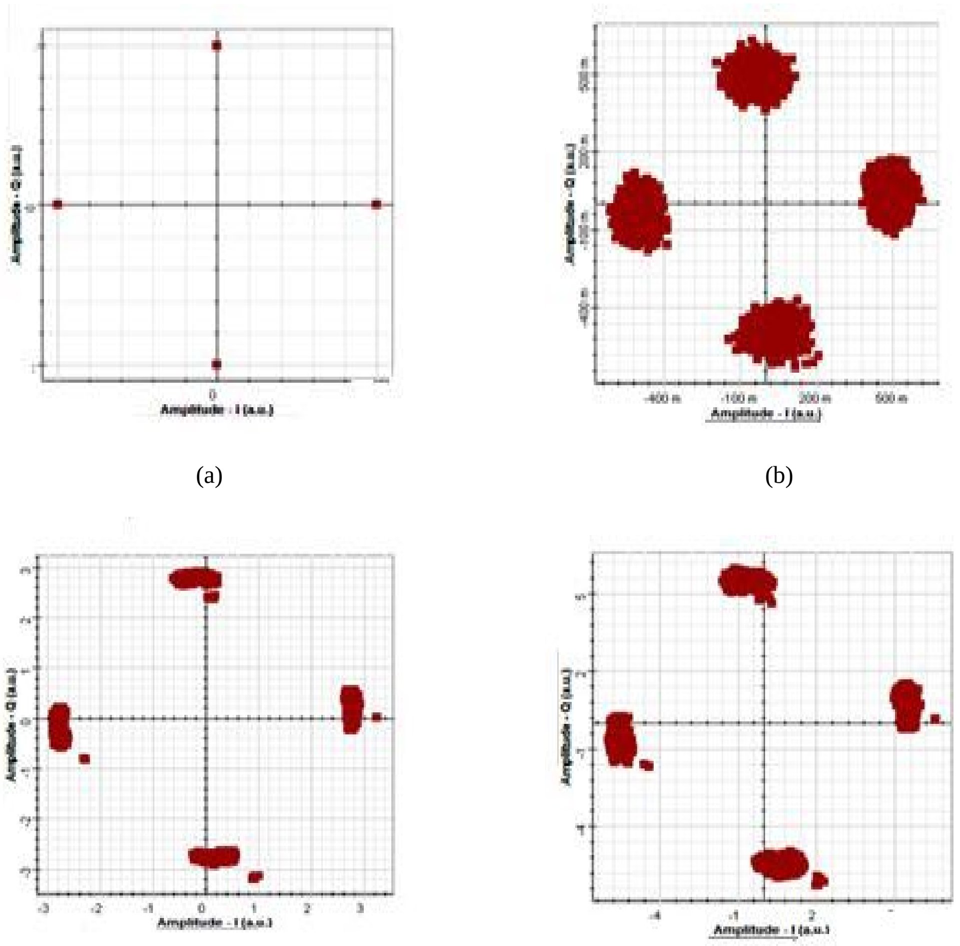


Figure.4 The variation in Q-factor

The effect of varying Q-factor for various dispersion compensation scheme configurations with respect to transmission distances has been observed. Figure 4. shows that symmetrical and post configuration is better for short distances, but for the long distance post configuration is preferable. The reception of the signal is better when we use DCF along with SMF and also the transmission distance increased with the use of dispersion compensation fiber. With the help of 6dBm it is observed that the faithful signal transmission is possible upto 100km without DCF but the transmission distance increases with the use of when we used the DCF in post configuration from 100 to 145km. With the increase in the transmission distance the Q-factor decreases due to attenuation non-linear effects in the area.

Case II. Effect of input power

In this the effect of input laser power with respect to Q factor has been studied. The input laser power is varied from -9dBm to +15dBm and output Q factor is calculated according to it.



(a)

(b)

(c)

(d)

Figure.5 Shows the constellation diagramsat (a) input signal, (b) output at Pin = − 9dBm, (c) output constellation diagram at 5dBm, (d) Shows the constellation diagram at 12dBm

The constellation diagram as shown in Figure.5 are used to examine the effect of variation of input laser power when the transmission distance is 50km and data rate is 10Gbps. The input constellation diagram and the output constellation diagram at -9dBm, 5dBm and 12dBm input powers are shown in the Figure 5. From these constellation diagrams it is pragmatic that, initially at -9dBm there is distortion in the signal, but with the increase in the power at 5dBm the distortion decreases, further increase in the power of 12dBm distortion starts dominating leads to deterioration of the transmitted signal.

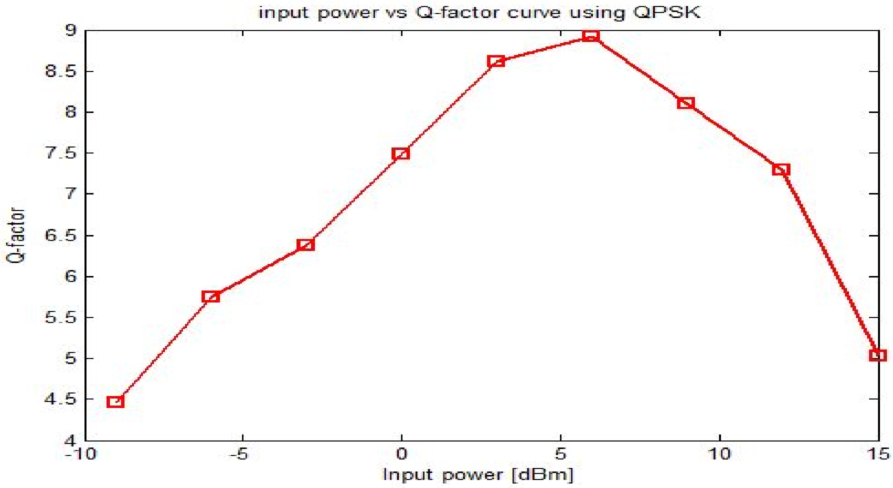


Figure.6 input power vs Q-factor curve

It has been observed that initially with the increase in the input laser power, the value of Q-factor increases and we receive better signal strength at the receiver end, but after reaching some threshold value the signal performance starts deterioration with the increase in input power and the Q- factor starts decreasing.

V. CONCLUSION

The transmission of optical signal over the CO-OFDM system has been demonstrated. Various parameters are illustrated. It has been concluded that the better reception of the signal obtained when we use the DCF in symmetrical and post configuration for short distances, but the signal reception is better when we use DCF in post compensation configuration for long distance. Then the effect of input laser power for reception of signal has been observed, it was concluded that the initials with the increase in input power the output signal reception is better at certain power level, but the further increase in power leads to deterioration of reception of signals, so certain threshold input power is there in which better signal is received at the output. It has been observed that the transmission distance increases from 100 - 145km when we use the DCF in post configuration along with SMF.

REFERENCES

[1] A. Peled and A. Ruiz, “Frequency domain data transmission using reduced Computational complexity algorithms, Acoustics, Speech, and Signal Processing,”*IEEE International Conference on ICASSP* vol. 5, pp.964 –967, 1980.

[2] Qi Pan, and R.J. Green, “Bit-Error-Rate Performance Of Lightwave Hybrid AM/OFDM Systems With Comparison With AM/QAM Systems In The Presence Of Clipping Impulse Noise,”*IEEE Photonics Technology Letters*pp. 278-280, 1996.

[3] J. Dixon, Bryn, Roger D. Pollard, and Stavros Iezekiel. “OFDM in wireless communication systems with multimode fiber feeds'. *IEEE transactions on microwave theory and techniques*vol. 49, no 8, 2001.

[4] Weinstein, S.B., “The History Of Orthogonal Frequency-Division Multiplexing History Of Communications”. *IEEE Communications Magazine*vol. 47, no.11, pp. 26-35, 2009.

[5] Lowery, Arthur, and Liang B.Du, “Optical Orthogonal Division Multiplexing For Long Haul Optical Communications: A Review Of The First Five Years”. *optical fiber technology*vol.17, pp. 421-438, 2011.

[6] Wang, Hui, and Deming Kong, “Performance Evaluation Of (D)APSK Modulated Coherent Optical OFDM System” *optical fiber technology*vol.19, pp. 242-249, 2013.

[7] Alatawi, Khaled, and Fahad Almasoudi. “Performance Study Of 1 Tbits/S WDM Coherent Optical OFDM System”. *Optic and Photonics Journal* vol 3, pp 330-335 2014.

[8] Anu Sheetal, Harjit Singh, and Ajay Kumar, “Stimulative Analysis Of 10Gbps Cohorent Detection Orthogonal Frequency Division Multiplexing Based Optical Communication System,”*International Conference on Communication, Computing & Systems*2014.

[9] Qiao and Yaojun, “Study On The Efficiency Of Eb/No Algorithm For BER Estimation Over112-Gb/S PDM CO-OFDM System With QPSK Mapping,”*optik*vol.125, pp. 799-804, 2014.

[10] Liu, And Xuejun, “Influence Of Fiber Link Impairments To Eb/No Estimation In CO-OFDM Systems With QPSK Mapping,”. *optik*vol. 124, pp. 1977-1981, 2013.

[11] Alatawi, khaled, and Fahad Almasoudi, “Integration Of Coherent Optical OFDM With WDM,” pp-25-29, 2013.

[12] Kaler, R.S, Ajay K.Sharma, and T.S Kamal. 'Comparison Of Pre-, Post- And Symmetrical-Dispersion Compensation Schemes For 10 Gb/S NRZ Links Using Standard And Dispersion Compensated Fibers'. *Optics communication*vol.209, pp. 107-123, 2002.

[13] Singh, Simranjit, and R.S Kaler. 'Comparison Of Pre-, Post- And Symmetrical Compensation For 96 Channel DWDM System Using PDCF And PSMF'. *optik* vol.124, pp. 1808-1813, 2013.

[14] Xianjie, Feng, and Li Yinfeng. 'CO-OFDM Technology Long Distance Transmission System'. *Journal of Applied Mathematics & Information Sciences* vol 2, pp.901-906, 2014.