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# 2nd Order PMD Compensation Using Polarization Controller with Different Modulation Techniques for 500 Gb/s Optical Transmissions

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## ABSTRACT

*This paper presents an experimental demonstration of 2nd order polarization mode dispersion (PMD) compensation using polarization controller with different modulation techniques (PM-QPSK and PM-16 QAM) for higher data rates.in optical communication for long haul distances. PMD compensation technique is used as it becomes more dominant at higher date rate. In this paper post compensation technique is used where an optical amplifier has been employed after fiber length span and a polarization controller in parallel combination with polarization delay. It prevents PSP from becoming frequency dependent, however it doesn't compensate the 2nd order PMD completely but to some extent so that signal could be retrieved at receiver properly after a long fiber span at high bit rate and the signal strength measured by Q-factor and BER values. The higher value of Q-factor different advanced modulation techniques are used and a higher value of Q factor shows that signal is retrieved at the receiver properly.*


***Keywords:-CD,DGD,OSNR,OTDM,PCD,PMD,PSP,QAM,QPSK,RZ,SOP***

## I. INTRODUCTION

For the past few years increasing the higher bit rate in optical fiber communication systems is very much demanded but high bit rate is diminished and limited by some type of dispersion like- chromatic dispersion, polarization effects and some fiber geometry perturbations. Increasing the bit rate by using polarization multiplexing technique and optical time division multiplexing (OTDM) of ultra-short optical pulses has been the topic of research. Over long distances the transmission of an ultrahigh-speed signal still remains a challenge, as the transmission of signal performance becomes highly assailable to chromatic dispersion (CD) and polarization-mode dispersion (PMD) [7,8]. Even if the both 1st order PMD that is nothing but DGD (differential group delay) and 2nd order PMD are completely compensated, the higher-order PMD has to be considered, because spectral width of transmitted pulse becomes wide.

It is well known that 2nd order PMD limits the performance of system especially for ultra-short pulses [10]–[12], as it arises from the frequency dependency of DGD and the principal state of polarization (PSP) in the fiber link. Frequency dependency of DGD results in polarization-dependent chromatic dispersion (PCD), it may be reduced with a conventional CD compensation method for individual polarization channels. The PSP of signal itself varies with frequency and becomes impossible to couple all the signal frequency components to the PSP simultaneously. The impairment caused by a constant DGD scales with the square of the bit rate, results in abrupt PMD induced in the high speed transmission systems [13-14]. Complementary features of PM and QPSK provide a way to achieve high bit rate. At this high bit rate, the PMD effects are very difficult to analyze due to its stochastic nature. Hence simulating the effects of PMD is not simple. Another combination of PM and 16 QAM technique provides a very data rate in optical communication considering the polarization mode dispersion as compared to PM-QPSK[20] technique it provides much good spectral efficiency and it has more tolerance against first and second order polarization mode dispersion.

There are different compensation methods which can be divided into different categories, depending on how the compensation method is performed weather electrically, optoelectronically or optically or weather the compensation is done before or after compensation (pre or post compensation). Optical post compensation method is currently an intense research field where both first order and higher order compensation have been taken into consideration. In the post compensation technique can be used up to any order. There are many more techniques in the market which provides very high bit rate over long haul distances in optical fiber communication but uses some PMD compensation technique as it becomes more dominant at very high bit rate (> 1Tbps) for long distances.

The previous technologies which were used for compensation of differential group delay (first order PMD) and chromatic dispersion (second order PMD) are pre-compensation PMD and post-compensation PMD [21] in which polarization mode dispersion was compensated before sending the data in to the fiber and after sending data respectively. In order to compensate higher order PMD there are many more techniques which comprises of different algorithms, a minor improvement of the robustness to PMD can be obtained by keeping the receiver threshold in the middle of the eye diagram degraded by ISI. The Modulation formats like return-to-zero (RZ) tolerates a slightly higher bit broadening due to PMD and thus further increase the maximal tolerable PMD.

## II EXPERIMENTAL SET UP

### 2.1 SIMULATION SETUP WITH RZ AND NRZ LINE CODINGS

In this set up the Pseudo random bit sequence generator is used to generate the bit rate of 500 Gbps which is given to NRZ/RZ pulse generator which provides the Gaussian shaped pulse feeded to direct modulated laser. The block diagram figure 1 and system model in OptiSystem figure2 are shown as below:-

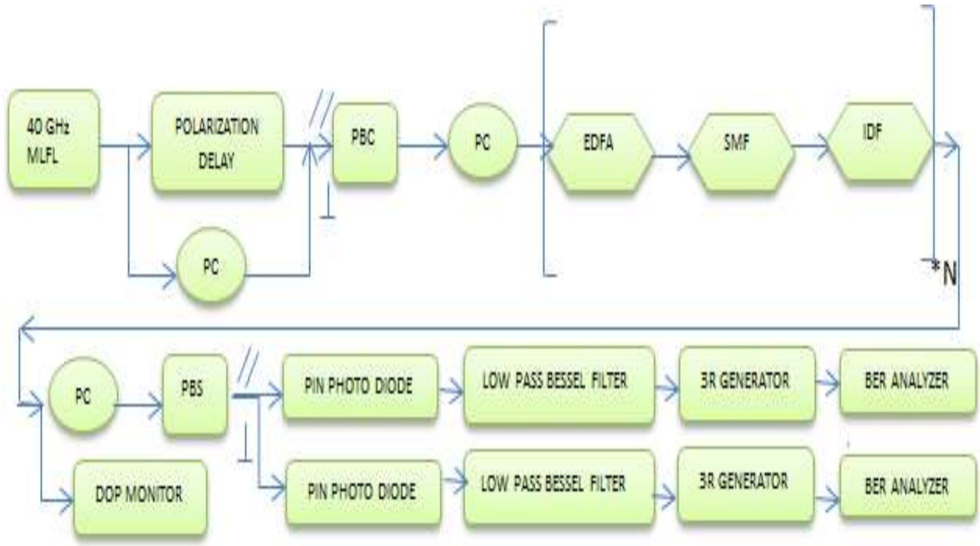


**Fig. 1.Block diagram with lines coding**

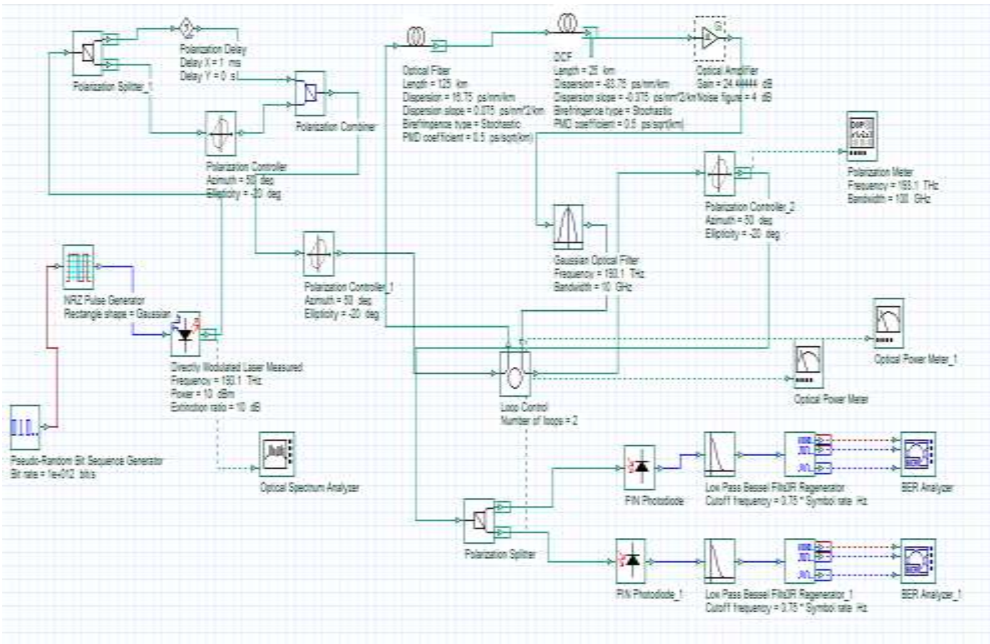

**Fig. 2.Simulation set up with line coding**

The combination of these three blocks works as a mode lock fiber laser which is used to generate a very high bit rate signal or a very narrow pulse width signal such as in Pico seconds which is required to send this high bit rate signal over long haul distances but it is drastically affected by polarization mode dispersion. As we know that the date rate up to 40 Gbps, 1st order PMD affects the signal but it can be compensated easily but beyond 40 Gbps 2nd order PMD comes in to the picture so the main aim is to compensate second order PMD for long haul distance for higher bit rate by making use of polarization controller however it doesn't compensates 2nd order PMD completely.

The signal coming from direct modulated laser is given to polarization splitter which splits the signal in to two

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orthogonal components which are feed to polarization delay and polarization controller respectively. Then again both components provided together to polarization beam combiner now this signal is given to polarization controller, by measuring degree of polarization through polarization controller PMD effect can be compensated to some extent now this signal is given to a span of 150 km single mode fiber which comprises of optical fiber (125 km) and a dispersion compensating fiber followed by optical amplifier which amplifies the signal. Now the length of the fiber is multiplied with the help of loop, then the signal is given to Gaussian optical filter which separates the signal from the noise that was created during signal travel through the fiber.

The signal then passes through polarization splitter which splits the signal and both components are given to PIN diode followed by low pass Bessel filter and the quality and strength of the signal is retrieved at the receiver that is measured by 3R Generator followed by BER analyzer. If the quality factor is greater than 6, it implies the signal is retrieved at the receiver properly without error or we can say that the more the eye opening the better the signal reception without errors.

**2.2SIMULATION SETUP WITH MODULATION TECHNIQUES**

**2.2.1 PM-QPSK BLOCK DIAGRAM and SIMULATION SET UP**

In this set up the Pseudo random bit sequencegenerator is used to generate the bit rate of 500 Gbps, which is given to NRZ/RZ pulse generator which provides the Gaussian shaped pulse feeded to direct modulated laser. Figure 3 shows the block diagram with PM-QPSK modulation technique and figure 4 shows simulation Set up for PM- QPSK modulation technique.

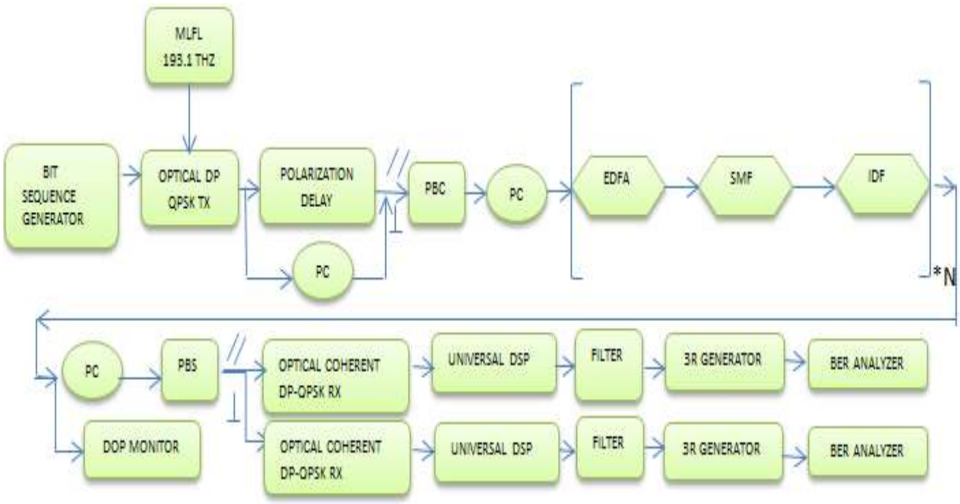


**Fig. 3. Block diagram with PM-QPSK modulation technique**

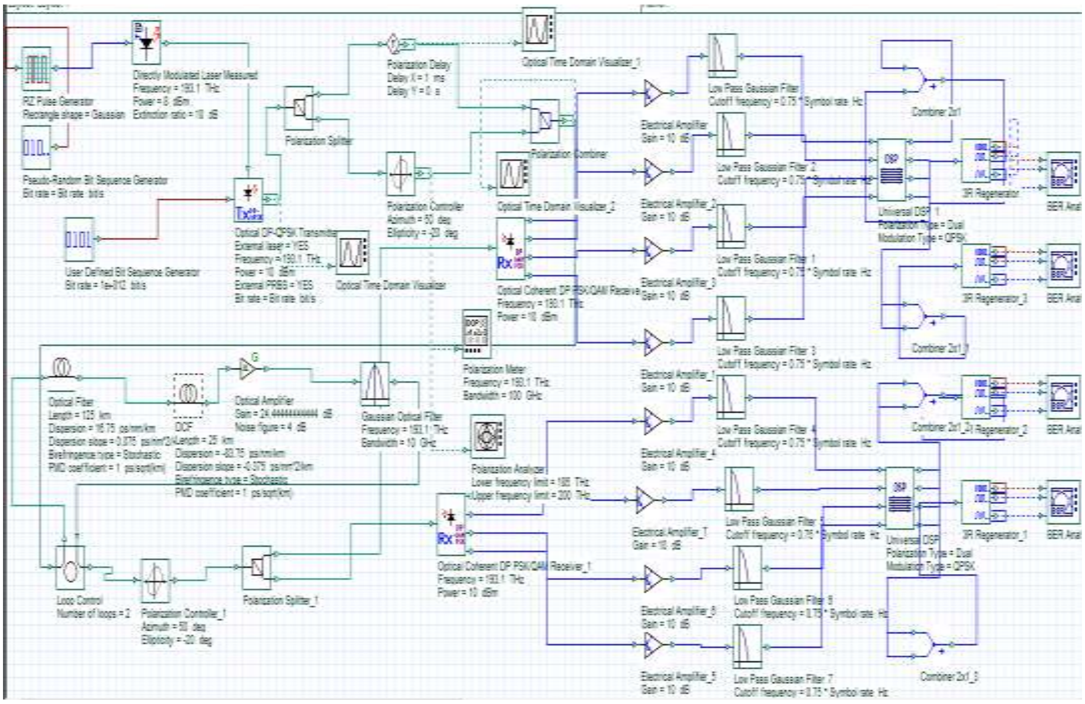

**Fig. 4.Simulation Set Up for PM- QPSK modulation technique**

The combination of these three blocks works as a mode lock fiber laser which is used to generate a very high bit rate signal or a very narrow pulse width signal such as in pico seconds which is required to send this high bit rate signal over long haul distances but it is drastically affected by polarization mode dispersion.

The signal coming from direct modulated laser is given optical DP QPSK transmitter which works at 193.1 terra hertz frequency now the modulated output is given to polarization splitter which splits the signal in to two orthogonal components which are feed to polarization delay and polarization controller respectively. Then again both components provided together to polarization beam combiner now this signal is given to polarization controller, by measuring degree of polarization through polarization controller PMD effect can be compensated to some extent now this signal is given to a span of 150 km single mode fiber which comprises of optical fiber (125 km) and a dispersion compensating fiber followed by optical amplifier which amplifies the signal. Now the length of the fiber is multiplied with the help of loop, then the signal is given to Gaussian optical filter which separates the signal from the noise that was created during signal travel through the fiber.

The signal then passes through polarization splitter which splits the signals which are feed to two different optical coherent DPQPSK receivers which are followed by electrical amplifiers low pass Gaussian filters and digital signal processing unit. The DSP unit has four outputs where two are in phase and other two are out of phases that are combined by four 2X1 combiners and given to 3R generator followed by BER Analyzer for checking the quality of the signal.

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### 2.2.2 PM-16 QAM SIMULATION SET UP and BLOCK DIAGRAM

The block diagram in figure 5 and simulation set up in figure 6 employ the Pseudo random bit sequence generator that is used to generate the bit rate of 500 Gbps. which is given to NRZ/RZ pulse generator which provides the Gaussian shaped pulse feeded to direct modulated laser.

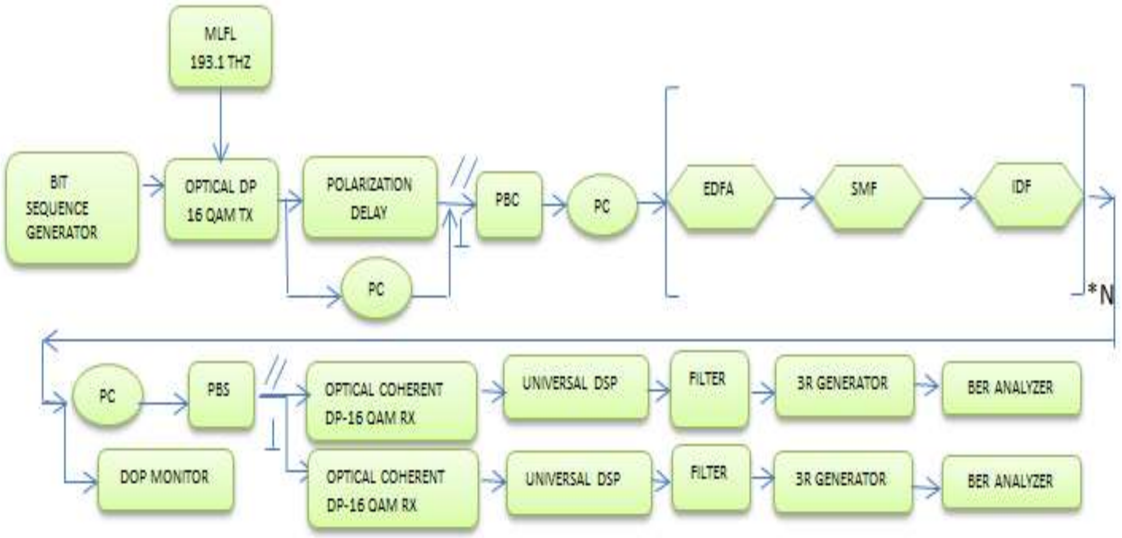


**Fig.5. Block diagram with PM-16 QAM modulation technique**

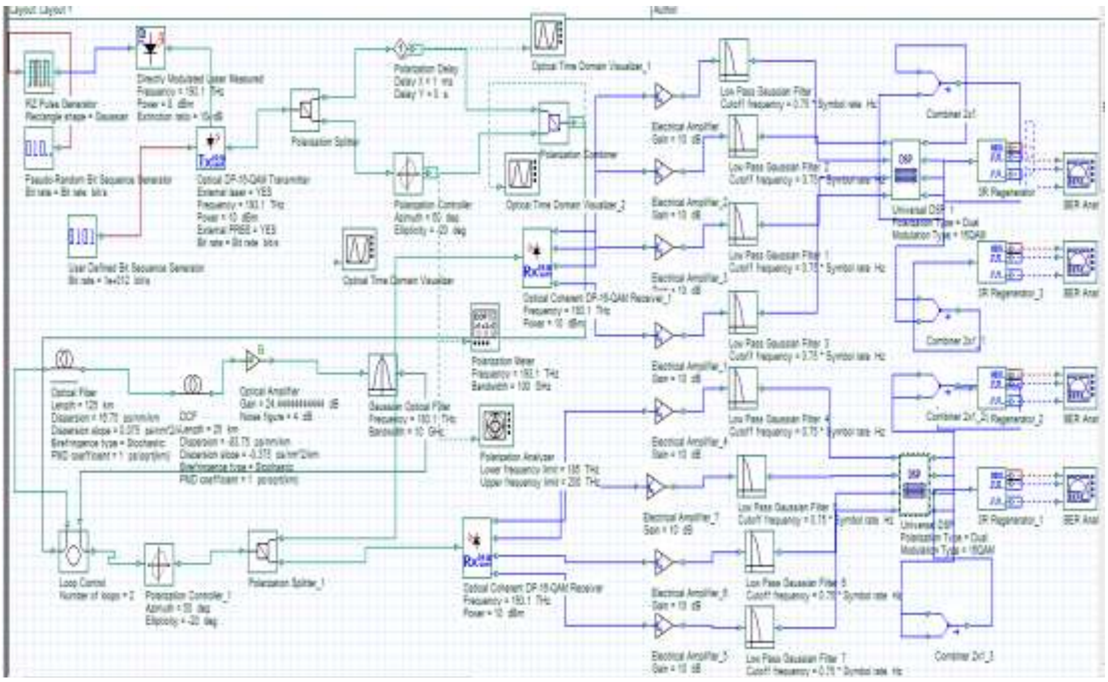

**Fig. 6.Simulation setup for PM-16 QAM modulation technique**

The combination of these three blocks works as a mode lock fiber laser which is used to generate a very high bit rate signal or a very narrow pulse width signal such as in pico seconds which is required to send this high bit rate signal over long haul distances but it is drastically affected by polarization mode dispersion.

The signal coming from direct modulated laser is given optical DP 16 QAM transmitter which works at 193.1 terra hertz frequency now the modulated output is given to polarization splitter which splits the signal in to two orthogonal components which are feed to polarization delay and polarization controller respectively. Then again both components provided together to polarization beam combiner now this signal is given to polarization controller, by measuring degree of polarization through polarization controller PMD effect can be compensated to some extent now this signal is given to a span of 150 km single mode fiber which comprises of optical fiber (125 km) and a dispersion compensating fiber followed by optical amplifier which amplifies the signal. Now the length of the fiber is multiplied with the help of loop, then the signal is given to Gaussian optical filter which separates the signal from the noise that was created during signal travel through the fiber.

The signal then passes through polarization splitter which splits the signals which are feed to two different optical coherent DP 16 QAM receivers which are followed by electrical amplifiers low pass Gaussian filters and digital signal processing unit. The DSP unit has four outputs where two are in phase and other two are out of phases that are combined by four 2X1 combiners and given to 3R generator followed by BER Analyzer for checking the quality of the signal.

## III.SIMULATION RESULTS

### 3.1. Q-FACTORS FOR PM-QPSK (USING RZ CODING) AT 500 GBPS BIT RATES

The figure 7 and figure 8show the Q factor values for the different variation of PMD Coefficient varying from zero to one for the 500Gbps bit rate for PM-QPSK modulation technique using RZ pulse code.

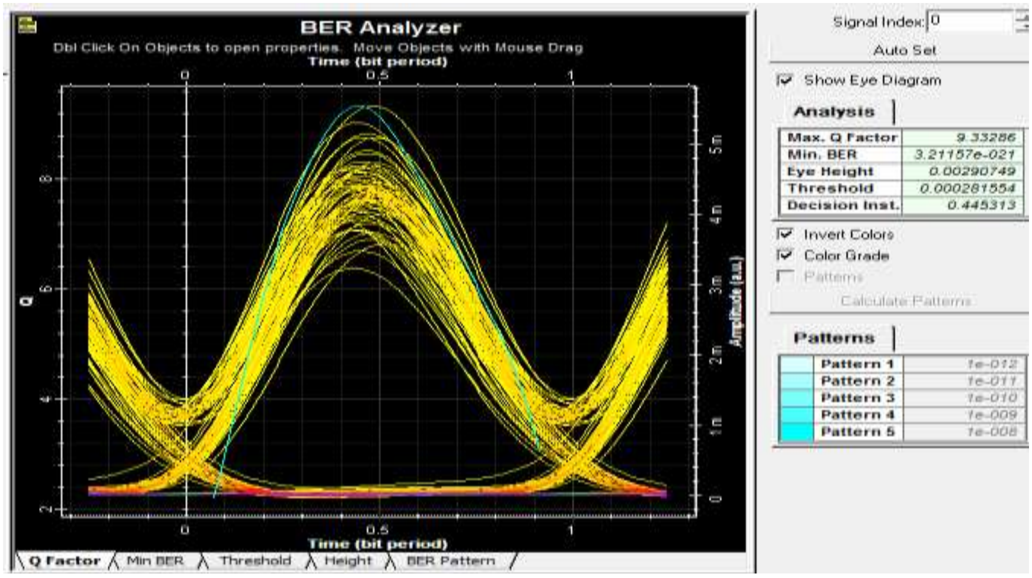


**Fig. 7 Eye diagram For PMD Coeff. =0**

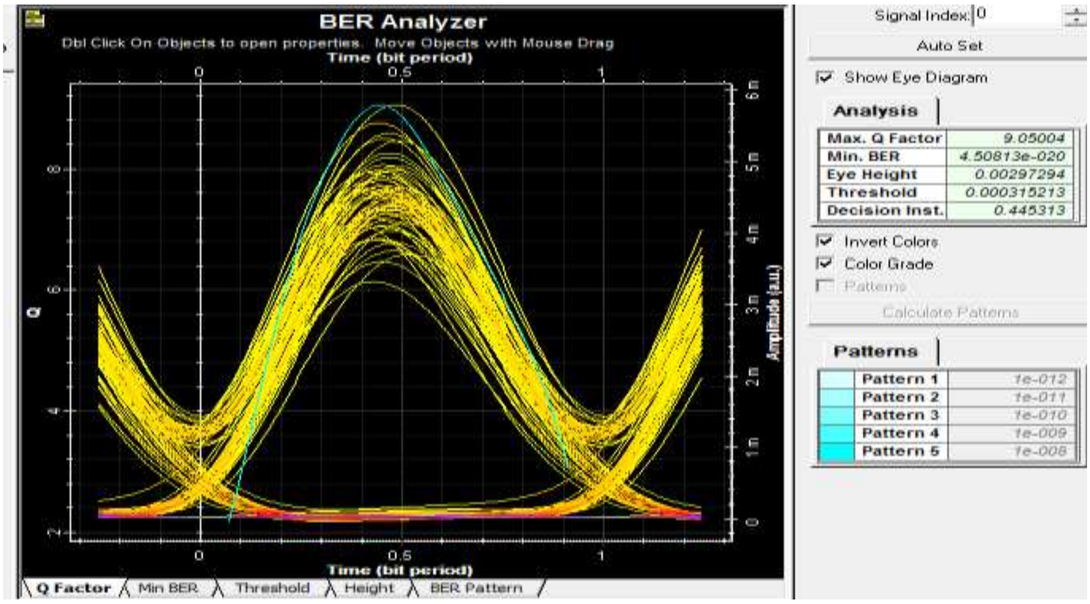


**Fig. 8 Eye diagram For PMD Coeff. =1**

It can be seen that at higher bit rate and at worst case of PMD coefficient q factor of signal is less.

### 3.2. Q-FACTORS FOR PM-QPSK (USING NRZ CODING) AT 500 GBPS BIT RATES

The figure 9 and figure10 show the Q factor values for the different variation of PMD Coefficient varying from zero to one for the 500Gbps bit rate for PM-QPSK modulation technique using NRZ pulse code.

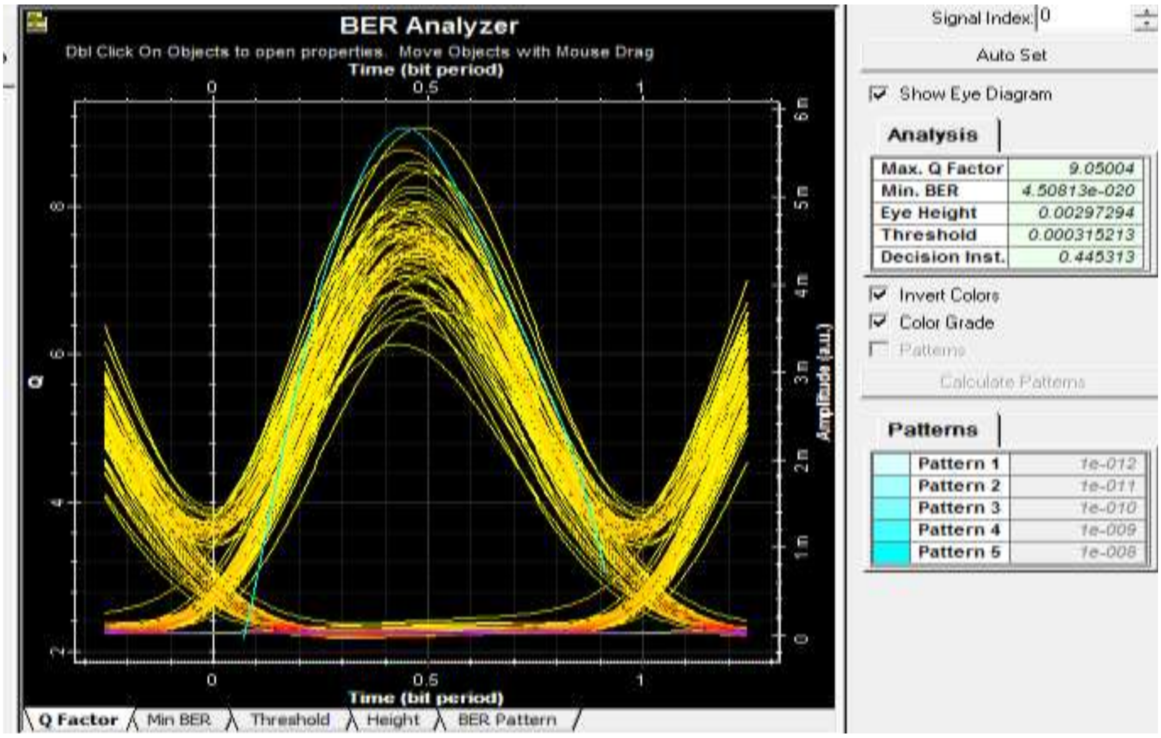


**Fig. 9Eye diagram For PMD Coeff. = 0**

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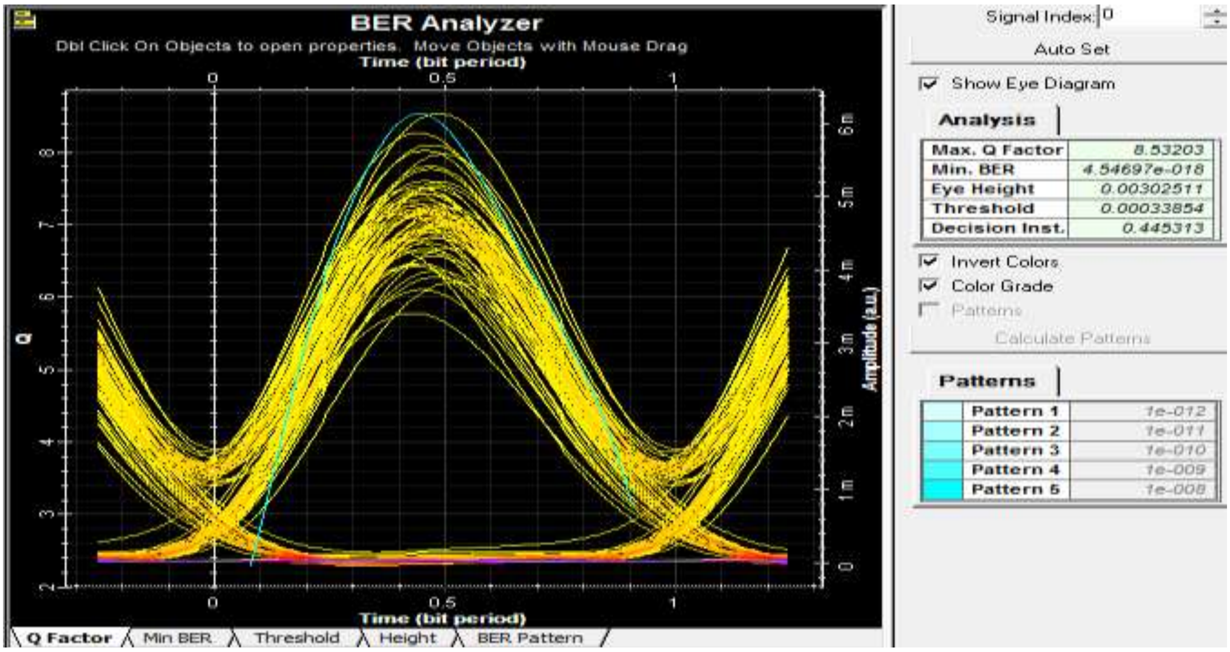


**Fig. 10 Eye diagram For PMD Coeff. =1**

It can be seen that at higher bit rate and at worst case of PMD coefficient q factor of signal is less.

### 3.3. Q-FACTORS FOR PM-16 QAM (USING RZ CODING) AT 500 GBPS BIT RATES

The figure 11 and figure 12 show the Q factor values for the different variation of PMD Coefficient varying from zero to one for the 500Gbps bit rate for PM-16 QAM modulation technique using RZ pulse code.

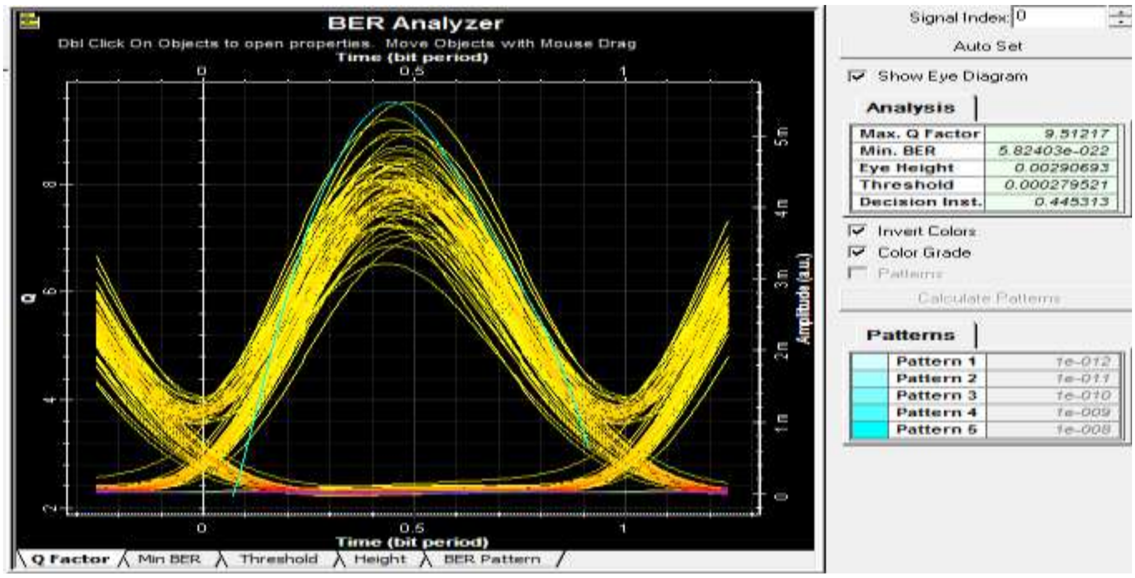


**Fig. 11 Eye diagram For PMD Coeff. =0**

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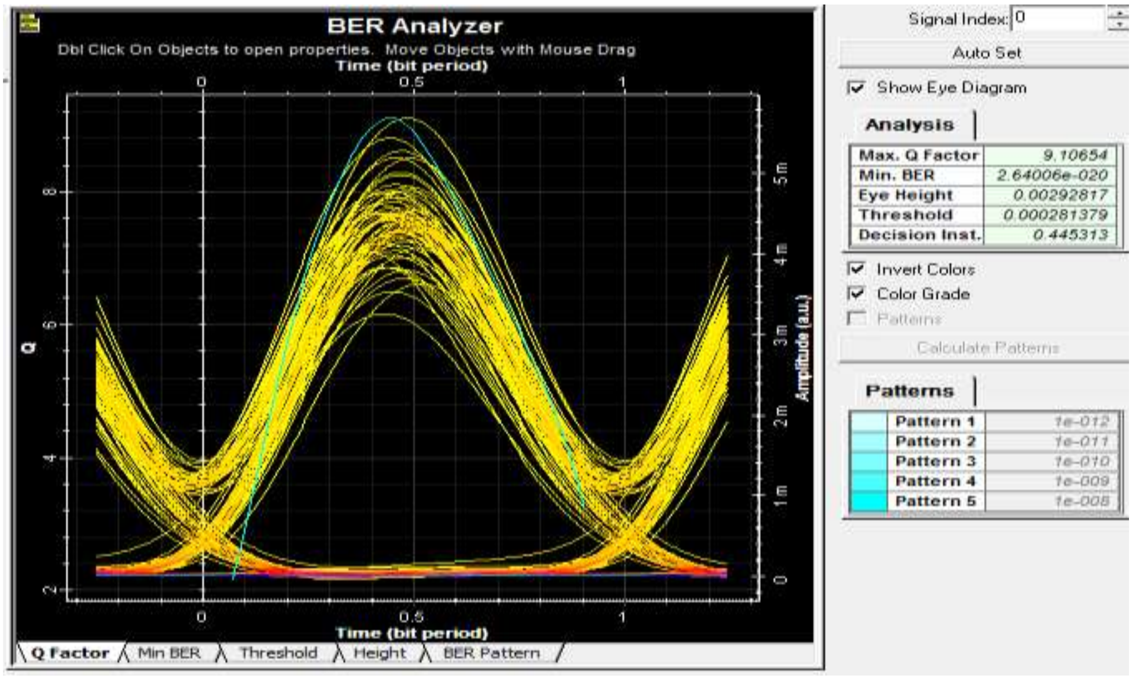


**Fig. 12 Eye diagram For PMD Coeff. =1**

It can be seen that at higher bit rate and at worst case of PMD coefficient q factor of signal is less.

### 3.3. Q-FACTORS FOR PM-16 QAM (USING NRZ CODING) AT 500 GBPS BIT RATES

The figure 13 and figure 14 show the Q factor values for the different variation of PMD Coefficient varying from zero NRZ to one for the 500Gbps bit rate for PM-16 QAM modulation technique using pulse code.

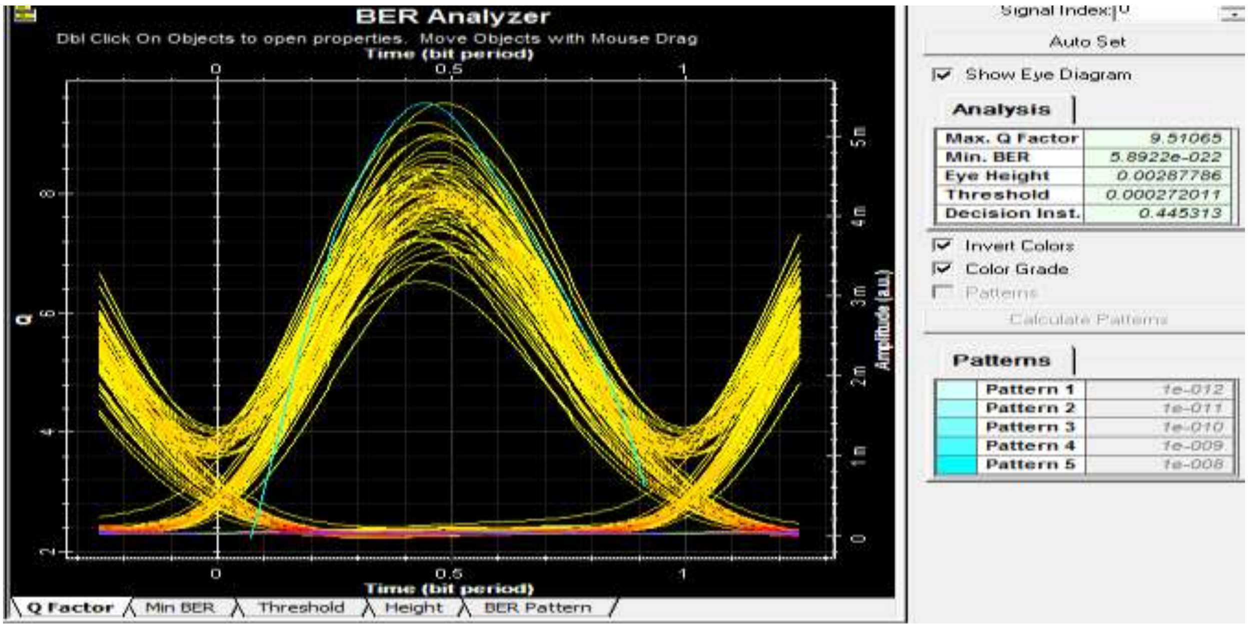


**Fig. 13 Eye diagram For PMD Coeff. =0**

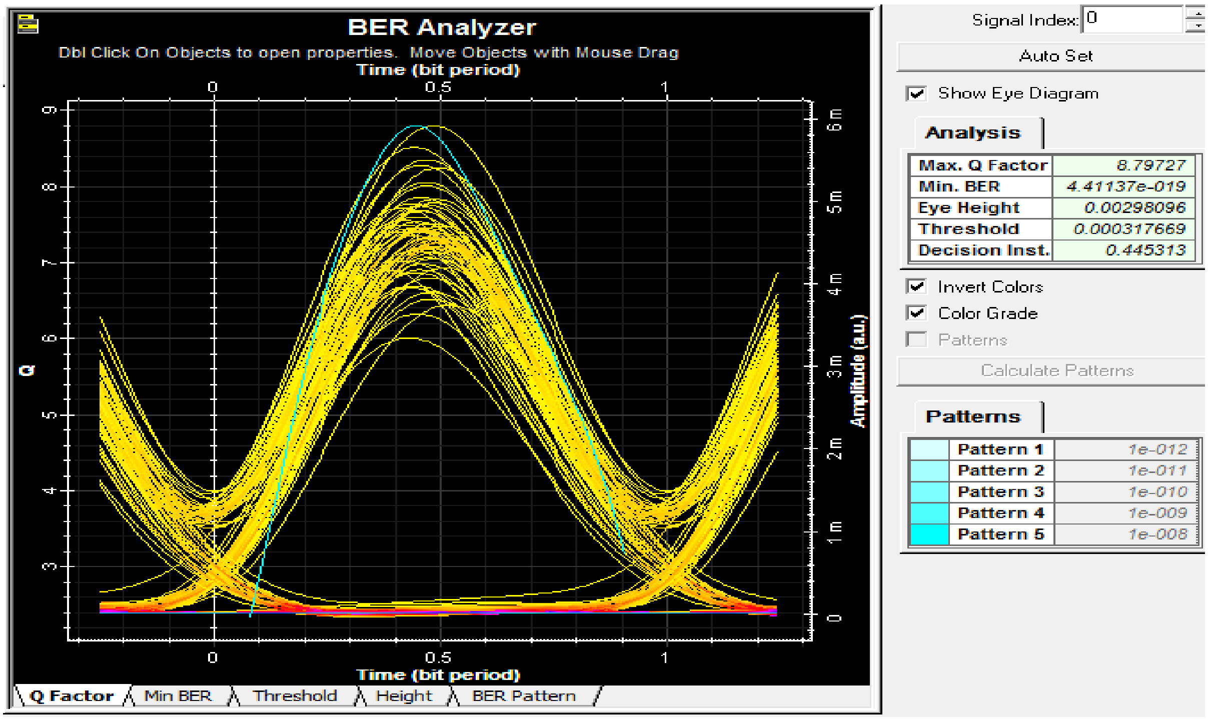


**Fig. 14 Eye diagram For PMD Coeff. =1**

It can be seen that at higher bit rate and at worst case of PMD coefficient q factor of signal is less.

### 3.4 MODULATION TEHNIQUES COMPARISON WITH RZ AND NRZ LINE CODING

Table 1 and table 2 show the comparisons betweenPM-QPSK and PM-16 QAM modulation technique with RZ and NRZ line codings in terms of Q factor and min BER while varying the PMD coefficient from 0 to 1.

**Table 1: Comparison between PM-QPSK and PM-16 QAM modulation technique with RZ line coding**

| PMD FACTOR VALUE | PARAMETERS | PM-QPSK MODULATION TECH. | PM-16 QAM MODULATION TECH. |
|---|---|---|---|
| 0 | Q-FACTOR | 9.33286 | 9.51217 |
| | MIN. BER | 3.2115e$^{-21}$ | 5.8240e$^{-22}$ |
| 1 | Q-FACTOR | 9.05004 | 9.10654 |
| | MIN.BER | 4.5081e$^{-20}$ | 2.6400e$^{-20}$ |

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**Table 2: Comparison between PM-QPSK and PM-16 QAM modulation technique with NRZ line coding**

| PMD FACTOR VALUE | PARAMETERS | PM-QPSK MODULATION TECH. | PM-16 QAM MODULATION TECH. |
|---|---|---|---|
| 0 | Q-FACTOR | 9.05003 | 9.51065 |
| | MIN. BER | $4.5080e^{-20}$ | $5.8922e^{-22}$ |
| 1 | Q-FACTOR | 8.53203 | 8.79727 |
| | MIN.BER | $4.5469e^{-18}$ | $4.4113e^{-19}$ |

### 3.4 COMPARISON CHART OF 2ND ORDER PMD COEFFICIENT VS. Q FACTOR

By observing the comparison chart it can be clearly seen that quality factor is having better value for PM-16 QAM modulation technique compared to PM-QPSK modulation technique while using different line codings.

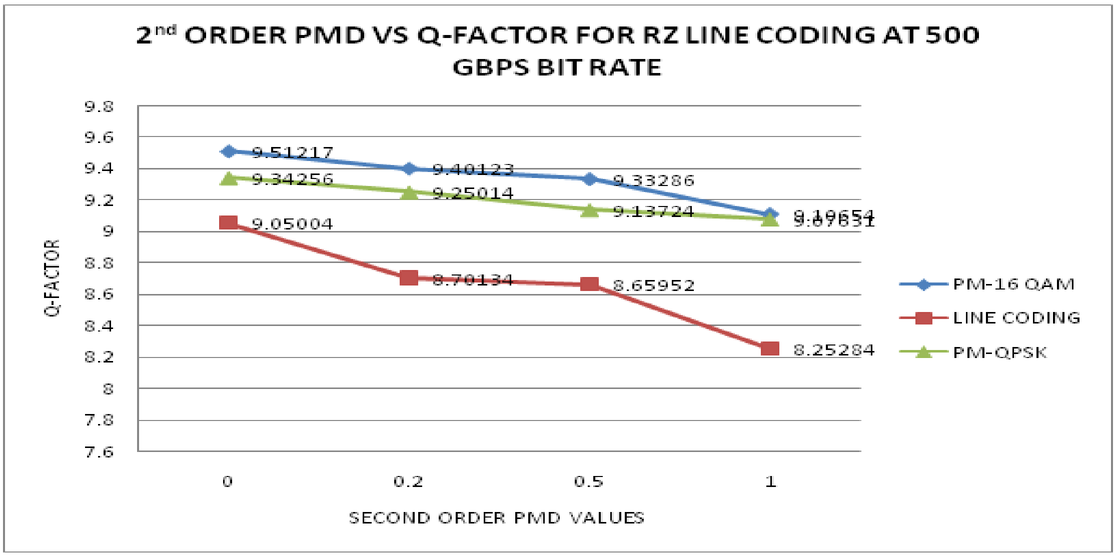


**Fig.15. 2nd order PMD coefficient Vs. Q factor at**

500 Gbps for different modulation technique with RZ pulse code.

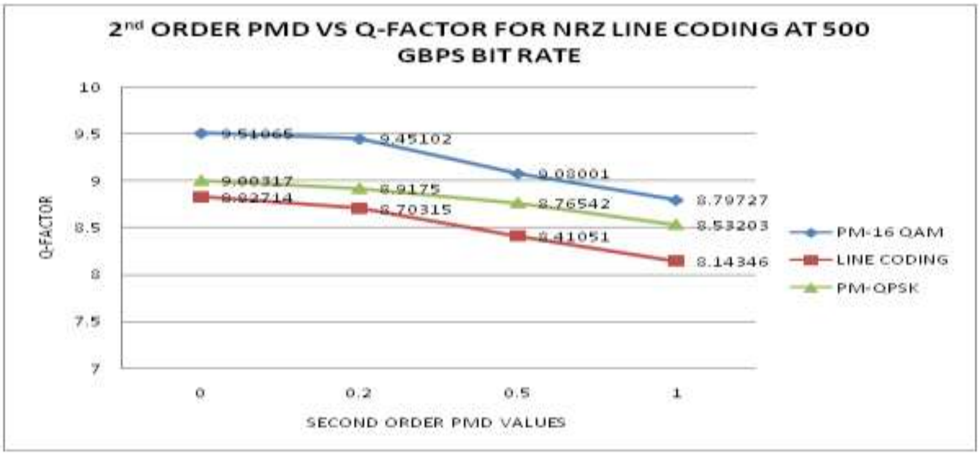


**Fig. 162nd order PMD coefficient Vs. Q factor at 500 Gbps for different modulation technique with NRZ pulse code.**

## IV.CONCLUSION AND FUTURE WORK

### 4.1 CONCLUSION

An extensive study on 2nd order PMD compensation using polarization controller on very high bit rate with or without advanced different modulation technologies such as PM-QPSK and PM 16 QAM has been performed. The previous technologies which were used for compensation of differential group delay (first order PMD) and 2nd order PMD are pre-compensation PMD and post-compensation PMD in which polarization mode dispersion was compensated before sending the data in to the fiber and after sending data respectively.

In order to compensate PMD there are many more techniques which comprises of different algorithms, and methods. Out of those compensation techniques this paper makes use of post compensation technique where an optical amplifier has been employed after fiber length span and a polarization controller in parallel combination with polarization delay which advances the slow axis of signal so that after travelling such long fiber length no DGD takes place and polarization controller controls the degree of polarization of the signal by matching principle state of polarization to sate of polarization so that 2nd order PMD can be compensated accordingly, and prevents PSP from becoming frequency dependent ,however it doesn't compensate the 2nd order PMD completely but to some extent so that signal could be retrieved at receiver properly after a long fiber span at high bit rate.

The results of this paper shows that as the value of second order PMD coefficient increases from 0 ps/sqrt(km) to 1 ps/sqrt(km) ,it has detrimental effects at high bit rate and becomes more dominant for degrading the data rate. While considering the variation of 2nd order PMD coefficient with or without modulations techniques for different modulation formats or line coding like RS/NRZ ,the quality of signal such that whether the signal is getting retrieved properly at output, can be measured. With advanced modulation scheme we are able to get greater Q factor even at the worst case of PMD coefficient which has been shown through different comparison charts.

### 4.2 FUTURE WORK

For achieving very high bit rate or to realize an ultra-high speed transmission over long distances, optimum pulse wave form, pulse width and different modulation formats could be chosen with different PMD compensation techniques.

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