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Comparative Analysis of PM-16 QAM and PM-QPSK Modulation Techniques for 500Gbps and 1Tbps Optical Transmission under 2nd Order PMD Effect

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Abstract

This paper presents a simulation based demonstration of comparison between different modulation techniques for higher bit rate transmission under the effect of 2nd order polarization mode dispersion (PMD). 2nd order PMD is more dominant at higher bit rate, therefore it thresholds the transmission of higher bit rate to some limit.

In this paper different modulation techniques have been compared on the ground of different signal parameters while varying the 2nd order PMD coefficient value from minimum to maximum. To compensate 2nd order PMD a post compensation technique is practiced in the simulation set up however it doesn't compensate the 2nd order PMD completely but up to some extent so that signal could be retrieved at receiver properly after travelling through a long fiber span. The signal strength is measured by some parameters eye diagrams, Q-factor and BER values. The more opening of eye shows the better signal quality, also the 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

1. Introduction

For as long as couple of years increasing the bit rate in optical fiber communication system has been the topic of intense research work.

Transmission of very high bit rate is reduced and restricted by some factors like-chromatic dispersion, polarization impacts and some fiber geometry disturbances.

Increasing the bit rate by utilizing polarization multiplexing strategy and optical time division multiplexing (OTDM) of ultra-short optical pulses has been the subject of research.

Over long distances the transmission of a ultrahigh-speed signal still remains a challenge, as the transmission of signal performance turns out to be exceedingly vulnerable to chromatic dispersion (CD) and polarization-mode dispersion (PMD) [7, 8]. Regardless of whether the both 1st order PMD that is nothing but DGD (differential gathering delay) and 2nd order PMD are totally compensated, yet higher order PMD must be considered, because spectral width of transmitted pulse turns out to be wide.

It is notable that 2nd order PMD limits the performance of system especially for ultra-short pulses [10, 11], as it emerges 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 might be diminished 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 [12].

Complementary features of PM and QPSK provide a way to achieve high data rate. At this high data 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 high data rate in optical communication considering the polarization mode dispersion as compared to PM-QPSK [13] 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 for getting higher bit rate, first depending on how the compensation method is performed whether it is electrically, optoelectronically or optically, second whether the compensation is done before or after compensation (pre or post compensation).

Optical post compensation method with effective modulation technique is currently an intense research field where both first order and higher order compensation have been taken into consideration. There are many more modulation techniques which provide 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 utilized for the compensation of 1st order (differential group delay) and 2nd order PMD are pre-compensation and post-compensation methods in which PMD effect was compensated before sending the data in to the fiber and after sending data respectively. In order to compensate higher order PMD there are various 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.

2. Simulation Set Up

2.1 PM-QPSK Block diagram and simulation set UP

Figure 1 and Figure 2 show the block diagram and simulation Set up with PM-QPSK modulation technique respectively.

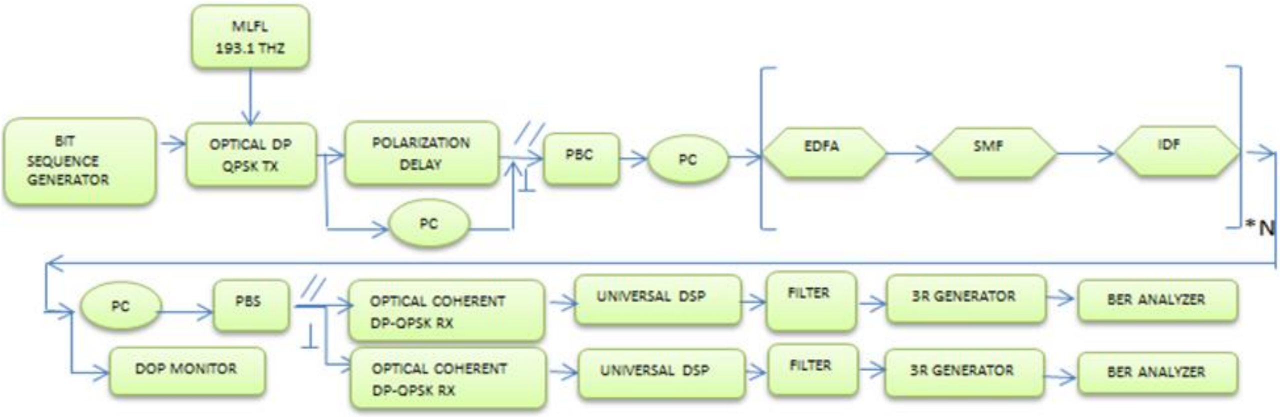

Fig 1: Block diagram with PM-QPSK modulation technique

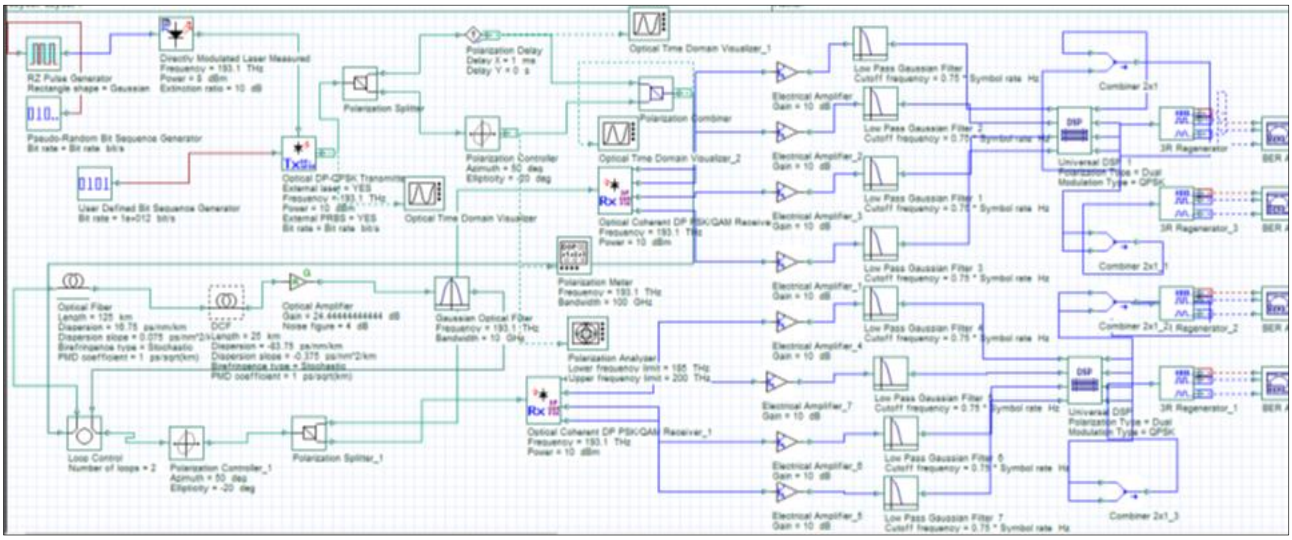

Fig 2: Simulation setup using PM- QPSK modulation technique

In the above given set up the Pseudo random bit sequence generator is used to generate the bit rate of 500 or 1000 Gbps which is provided to NRZ/RZ pulse generator that gives the Gaussian shaped pulse feeded to direct modulated laser.

The combination of these three blocks works as a mode lock fiber laser which is used to generate a very high bit rate signal having very narrow pulse width in Pico seconds.

The signal coming from direct modulated laser is given to optical DP QPSK transmitter working at 193.1 terra hertz frequency, the modulated output is given to polarization splitter which splits the signal in to two orthogonal components which are feeded to polarization delay and polarization controller respectively.

The polarization beam combiner combines both components and provides it to polarization controller, where by measuring degree of polarization by polarization controller, PMD effect can be compensated to some extent.

The 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.

The length of the fiber can be increased with the help of loop and then the signal is given to Gaussian optical filter which separates the signal from the noise that was added to the signal.

The signals from polarization splitter feeded to two different optical coherent DP-QPSK receivers which are followed by electrical amplifiers, low pass Gaussian filters and digital signal processing unit. The DSP unit has four outputs, out of them two are in phase and other two are out of phase, combined by four 2X1 combiners and given to 3R generator followed by BER analyzer for checking the quality of the signal.

2.2 PM-16 QAM simulation SET UP and Block Diagram

The block diagram in figure 3 and simulation set up in figure 4 employ the Pseudo random bit sequence generator that is used to generate bit rate of 500 or 1000 Gbps which is given to NRZ/RZ pulse generator that provides the Gaussian shaped pulse feeded to direct modulated laser.

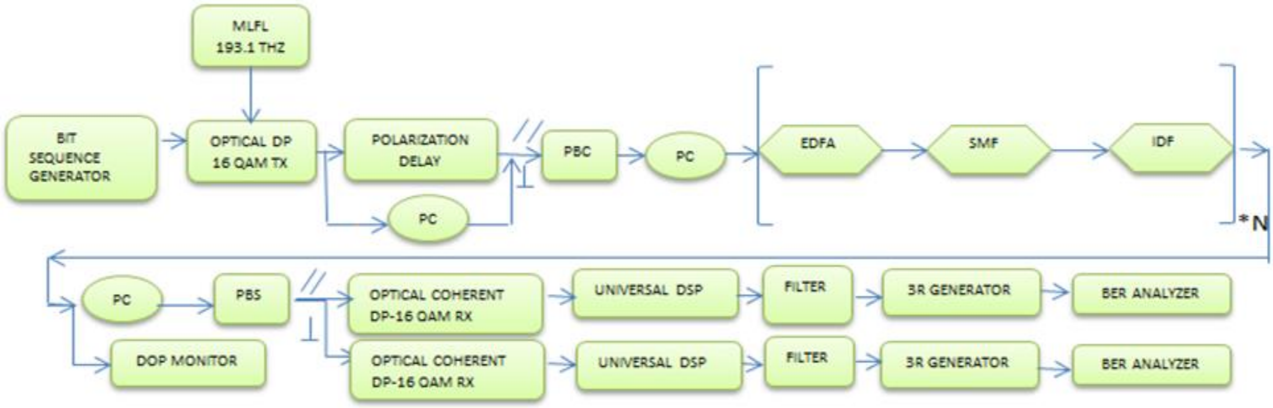

Fig 3: Block diagram with PM-16 QAM modulation technique

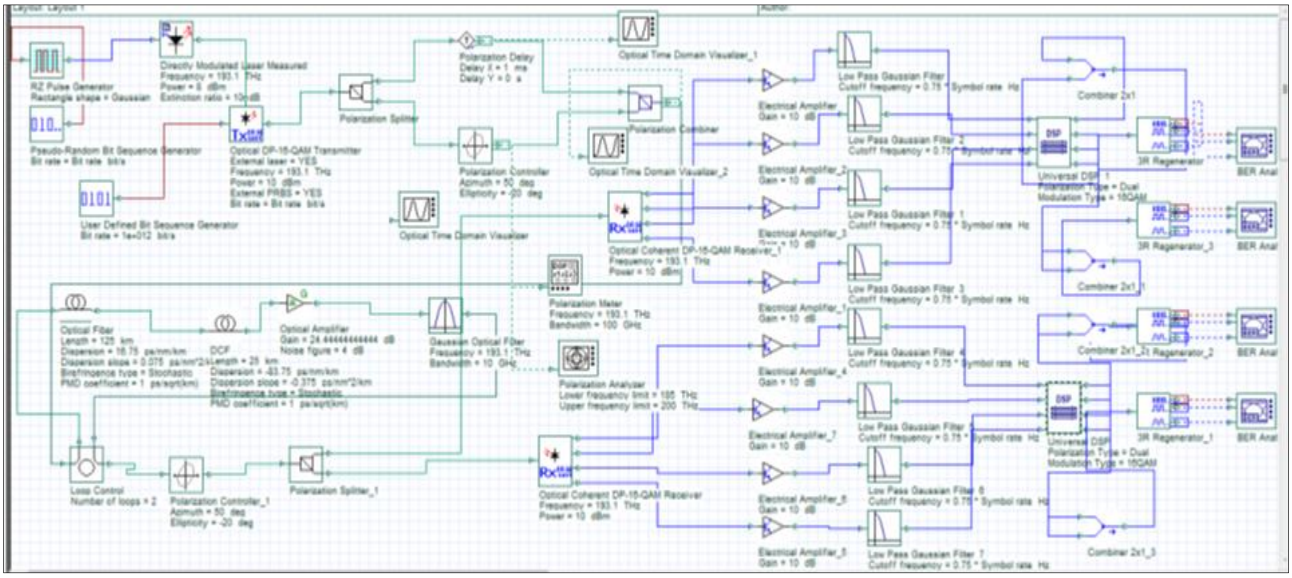

Fig 4: Simulation setup for PM-16 QAM modulation technique

The signal coming from direct modulated laser is applied to optical DP 16 QAM transmitter which works at 193.1 Terra hertz frequency, the modulated output is provided to respective block in the same manner as described earlier.
The signals from polarization splitter feeded 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 which are combined by four 2X1 combiners and given to 3R generator followed by BER analyzer for checking the quality of the signal.

3. Simulation results

3.1 Comparison between modulation Techniques using RZ and NRZ line Coding's at different bit rates

Table 1 and table 2 show the comparisons between PM-QPSK and PM-16 QAM modulation technique with RZ and NRZ line codings at 500 Gbps bit rate in terms of Q factor and min BER while varying the PMD coefficient from 0 to 1. Whereas Table 3 and table 4 show the comparisons between PM-QPSK and PM-16 QAM modulation technique with RZ and NRZ line codings at 1000 Gbps bit rate.

Table 1: Comparison between PM-QPSK and PM-16 QAM modulation technique at 500Gbps 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	$4.5081e^{-20}$	$2.6400e^{-20}$

Table 2: Comparison between PM-QPSK and PM-16 QAM modulation technique at 500 Gbps 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	$4.5469e^{-18}$	$4.4113e^{-19}$

Table 3: Comparison between PM-QPSK and PM-16 QAM modulation technique at 1000 Gbps with RZ line coding

PMD Factor Value	Parameters	PM-QPSK Modulation Tech.	PM-16 QAM Modulation Tech.
0	Q-Factor	7.48166	7.55255
	Min. Ber	$3.6675e^{-14}$	$2.13356e^{-14}$
1	Q-Factor	6.67048	7.12223
	Min.Ber	$1.2707e^{-11}$	$5.2986e^{-13}$

Table 4: Comparison between PM-QPSK and PM-16 QAM modulation technique at 1000 Gbps with NRZ line coding

PMD Factor Value	Parameters	PM-QPSK Modulation Tech.	PM-16 Qam Modulation Tech.
0	Q-Factor	7.01621	7.40267
	Min. Ber	$1.1370e^{-12}$	$6.6670e^{-14}$
1	Q-Factor	6.07089	7.01621
	Min.Ber	$6.3390e^{-10}$	$1.1370e^{-12}$

3.2 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.

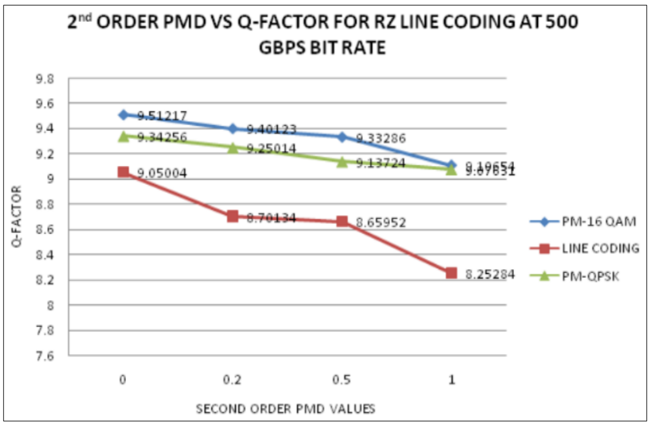

Fig 5: 2nd order PMD coefficient Vs. Q factor at 500 Gbps for PM-QPSK and PM-16 QAM modulation techniques with RZ pulse code.

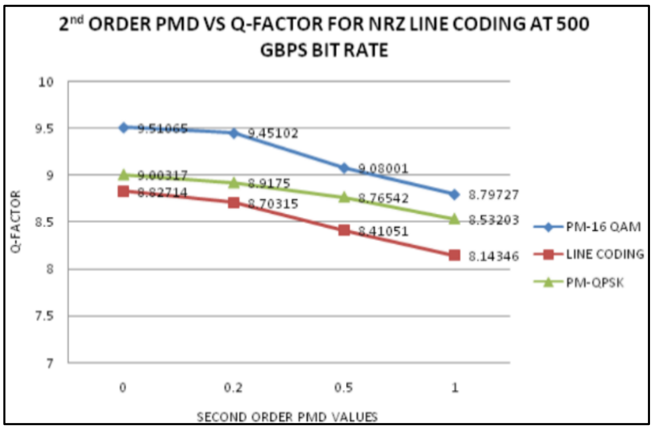

Fig 6: 2nd order PMD coefficient Vs. Q factor at 500 Gbps for PM-QPSK and PM-16 QAM modulation techniques with NRZ pulse code.

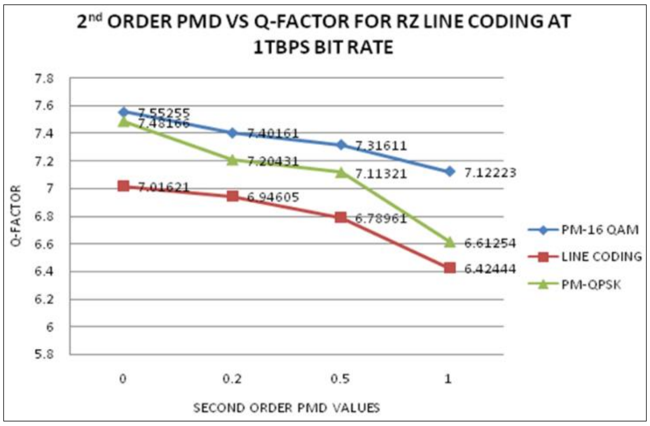

Fig 7: 2nd order PMD coefficient Vs. Q factor at 1000 Gbps for PM-QPSK and PM-16 QAM modulation techniques with RZ pulse code

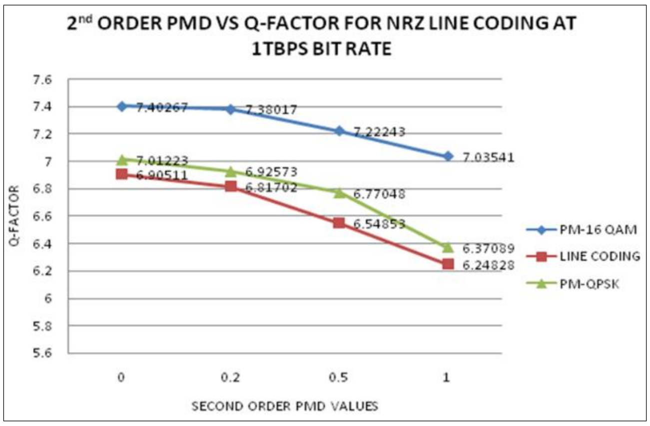

Fig 8: 2nd order PMD coefficient Vs. Q factor at 1000 Gbps for PM-QPSK and PM-16 QAM modulation techniques with NRZ pulse cod

4. Conclusion and future work

4.1 Conclusion

A comparative study of different modulation techniques (such as PM-QPSK and PM-16 QAM) under the effect of 2nd order PMD at very high bit rate has been performed. Many modulation technologies have been used under PMD effect in order to get better signal quality at receiver end.

In order to compensate PMD and get a good quality factor there are many more techniques which comprise of different algorithms, modulation techniques and methods. Out of those techniques this paper makes use of PM-QPSK and PM-16 QAM modulation technique with post compensation method 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 0ps/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 RZ/NRZ ,the quality of signal such that whether the signal is getting retrieved properly at output or not, 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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