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# OLP Limits of DSP Based 400 Gbps DP 16-QAM Modulation in Non Linear Fiber Propagation

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## Abstract:

The effects of optical nonlinearities in optical fibers are ubiquitous. These effects can be deleterious, but also have many useful applications, especially in the field of implementing all-optical functionalities in optical networks. The paper is devoted to modeling the evolution of signal at 400 Gbps during non linear propagation for DP 16-QAM modulation format in order to show the impact of optical launch power and fiber span transmission on the propagation. This study is focused on the non linear propagation of fiber to obtain the relationship between Optical Launch Power (OLP) and Error Vector Magnitude (EVM). It is found that the for the range of launch power (-8dBm to 4dBm) ,  EVM is below 16%.

**Keywords: DP. EVM. OLP. QAM.**

## I. Introduction

In fiber optical communication systems, the evolution of advanced digital modulation formats such as Quadrature Phase Shift Key (QPSK) and Quadrature Amplitude Modulation (QAM) have been seen as a promising alternative to boost the capacity of optical communication systems. But new limitations arise with every new alternative. The channels of fiber optic system are limited by linear and non linear impairments. Linear impairments include Chromatic Dispersion (CD) and Polarization Mode Dispersion (PMD), and non linear impairments which include Self Phase Modulation (SPM), Cross Phase Modulation (XPM) and Four Wave Mixing (FWM) [1,2]. The noise produced in Erbidium Doped Fiber Amplifiers causes the self phase modulation to change in a random fashion and is also called Non Linear Phase Noise [3]. This noise becomes the dominant source of symbol errors at the receiver during demodulation. So, it is necessary to compensate NLPN and other linear and non linear impairments at both transmitter and receiver. Keang Po-Ho in [4] stated that Non linear phase noise which is also called the Gordon-Mollenauer effect can be electronically compensated by subtracting a portion proportional to received intensity from the received phase. This compensation halves the standard time deviation of the residual non linear phase shift , allowing doubling of number of fiber spans and the transmission distance. In [5], by taking the inverse Laplace transform of its moment generating function, an asymptotic approximation of the probality density function of the normalized non linear phase noise is derived by using the method of steepest descent. Comparing this method with the analytical and numerical results showed that the steepest descent method gives more accurate results.

In [6], R.Hui et.al demonstrated that for systems operating at normal dispersion, non linearity when compared with linear propagation reduces the deleterious impact of amplified spontaneous emission noise. In [7], W.P./Ng et.al demonstrated that LTE-RoF system experiences severe nonlinear distortion for OLP value less than 6 dBm, while both linear and non linear distortions increases linearly with the transmission distance. They also concluded that there is a specific power range for which systems performs optimally. J.Toulous in [8] described the effect produced by each kind of non linearity such as self-phase modulation (SPM), cross-phase modulation (XPM), four-wave mixing (FWM), stimulated Raman scattering (SRS) and emphasized their variations for different values of essential parameters. In [9], L. G. L. Wegener, et. al designed a model which compensate the effects of dispersion and absorption during propagation. The results concluded that the capacity does not increase arbitrarily with increasing signal to noise ratio, rather the capacity ultimately falls with increasing signal strength.

As per our knowledge, no author has discussed the optical launch power limits for DP 16-QAM at 400 Gbps. So in our paper, we have investigated the performance of DP 16-QAM at a bit rate of 400 Gbps for fiber nonlinearities by evaluating EVM with respect to launch power. We have practically revealed three optical power transmission regions, namely linear, intermixing and nonlinear regions. Also, we have demonstrated that intermixing region is optimal as compared to other two regions.

The remaining of the paper proceeds as follows: in section 2, simulation set up for the system is described. In section 3, results and discussions which specify the optimal region and EVM values obtained for different optical power. The results are discussed with help of spectrum analyser, electrical constellation diagrams and graphical representation. In section 4, the conclusion is given.

## II. System set-up:

Fiber non-linearity in optical fiber communication has been found to be one of the limiting factors as channel capacity requirement continues to grow [10]. High spectral efficiencies can be achieved by 16-QAM, so it is widely used in optical communications as compared to QPSK or other modulation formats. The non linear response of optical fiber communication will emit additional factitious signals [7].

Fig.1 shows the experimental set up for the 400-Gbit/s 16-QAM transmission. An externally modulated continous wave laser with an emission wavelength of 1550 nm and a linewidth of 0.1 Mhz was employed as a light source. Attenuator attenuates or enervates the input signal. This signal is transmitted to single mode fiber which has attenuation of 0.2 dB/km and dispersion of 16.75 ps/nm-km and dispersion slope of 0.075 ps/km-nm$^2$ . The transmission channel used in this system is SMF. The SMF model follows the properties of dispersion, and non-linear Schrodinger equation expresses the non linear propagation. [11]

$$\frac{\partial s}{\partial T} = [Q(L,t) + P(L,t) + R(L,t)] * S(L,t)]$$

(1)

(1)

Where,

$$Q(L,t) = -\frac{j}{2}\beta_2 \frac{\partial S^2(L,t)}{\partial T^2} - \frac{\alpha}{2}$$

$$P(L,t) = j\frac{2\pi}{\varphi} n\, |S(L,t)|^2$$

$$R(L,t) = \frac{g_B}{2A_{eff}} |S_n(L,t)|^2\, \partial(w - w_c) - \frac{\beta_1}{2}$$

And S(L,t) is the OLP after propagating through L transmission span of SMF. Q(L,t) is the linear operator, P(L,t) and R(L,t) are the non linear operators for SPM and SBS respectively. $\beta_2$ is the second order dispersion coefficient, $\alpha$ is the SMF attenuation coefficient, $\varphi$ is the optical wavelength,n2 is the nonlinear refractive index, $g_B$ is the SBS gain, $A_{eff}$ is the effective area, $S_n(L,t)$ is the reflected signal, and $\beta_1$ is the spontaneous emission parameter.

Table 1. Simulation parameters

| Parameters | Values |
|---|---|
| Modulation | 16-QAM |
| Central Frequency | 1550 nm |
| Sensitivity | -100 dBm |
| Resolution | 0.1 nm |
| Optical Power | -10 dBm to 24 dBm |
| SMF length | 100 km to 130 km |
| PD responsivity | 1 A/W |
| EDFA gain , noise figure | 10 dB, 4dB |

This signal is then boosted to the desired power level for transmission through N amplified fiber spans with the help of EDFA. The parameters for EDFA include gain = 10 dB, noise figure = 4 dB and noise bandwidth of 13 THz. First the Gaussian filter output was directed to electrical filters and then to optical coherent DP-16 QAM receiver which simulates an optical coherent receiver for dual-polarization 16-QAM signals based on a homodyne design. Electrical amplifiers with a gain of 85 dB boost the optical signal to the desired power level for transmission through N amplified fiber spans. Digital signal processing is used to mitigate the effects of nonlinearities. DSP component performs several important functions to aid in recovering the incoming transmission channel after coherent detection.

QAM sequence decoder decodes two parallel QAM M-ary symbol sequences to a binary signal. The signals from those decoders is coupled into parallel to serial converter which combines two input sequences at bit rate 'R' into one output sequence at '2R' bit rate. The output is generated by BER analyzer, which generates a large bit sequence, transmits the bit sequence to device under test and then compares the bit sequence it received from device under test to the transmitted bit sequence.

## 3. Results and discussions

In this section, the impact of non linear propagation from -19dBm to 14 dBm on a DP 16-QAM simulation set up is described.

The spectrum analysis for the power of -10dBm, 10 dBm and 24 dBm at 100 km at the transmitter are shown in fig.2(a), (b), (c) respectively. From these graphs, it is depicted that in figure 2(b) and 2(c), the effect of SPM and XPM are more dominant.
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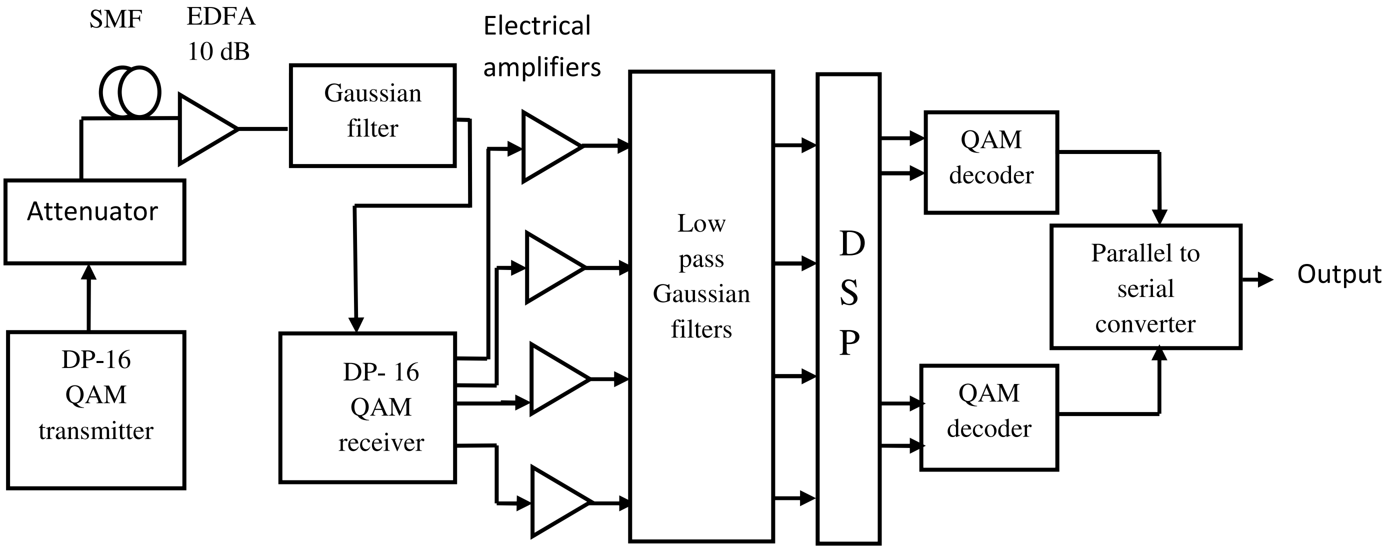
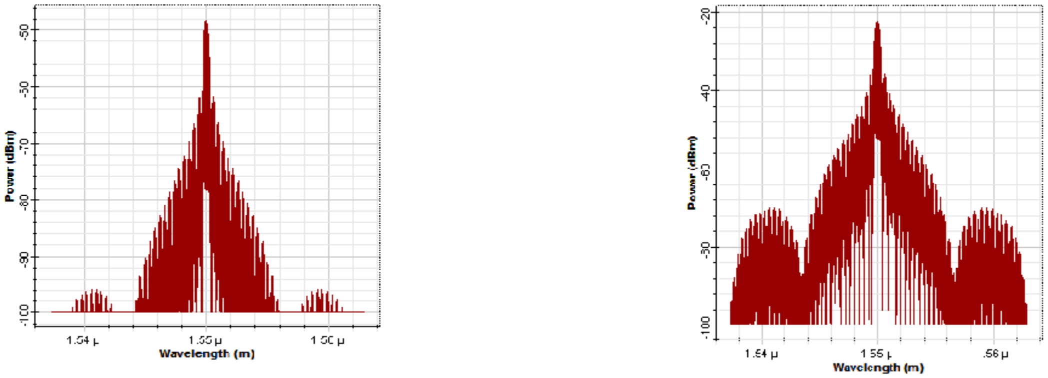
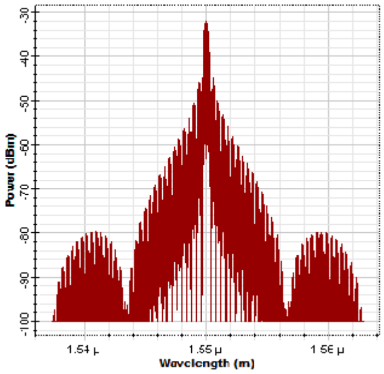


Fig. 1 System set up of 400 Gbps DP-QAM using DSP.



(a)

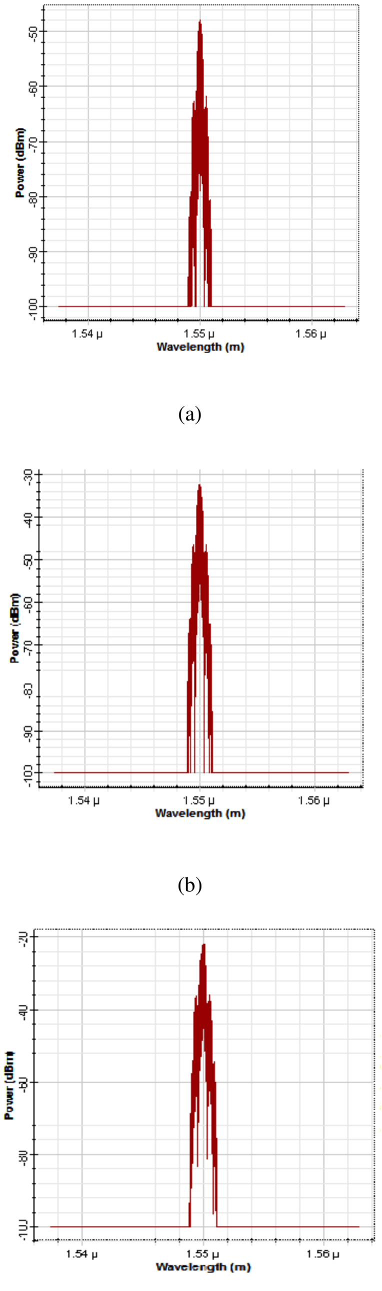
(c)



(b)

Fig.2 Spectrum analysis at the transmitter for OLP of (a)-19dBm (b) 0.1 dBm (c) 14 dBm at 100 km

The spectrum analysis at the receiver for 100 km for the power values of -19 dBm, 0.1 dBm and 14 dBm are represented in fig.3 (a), (b), (c) respectively. At a wavelength of 1.55 $\mu$, the values of power for (a),(b) and (c) are -54dBm, -27 dBm and -18 dBm respectively. As value of $\beta_2$ is -20, SPM is dominating because as the pulse width decreases, the receiver sensitivity also decreases. So,Fig. (b) and (c) show widened spectrum.



(a)

(b)

(c)

Fig.3 Plot showing power versus wavelength for the power of (a)-19dBm (b) 0.1 dBm (c) 14 dBm at 100 km at the receiver using spectrum analyser

The coherent receiver offers a simple method of monitoring the transmitted signal quality by plotting the amplitude of the signal on the two-dimensional plane. Fig. 4 shows the analysis obtained before the DSP unit. This represents that signal is effected by noise.

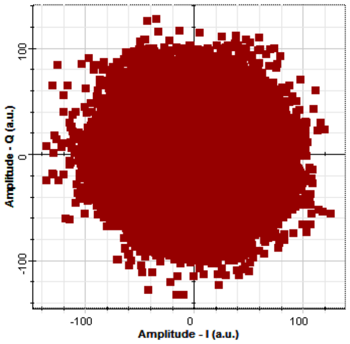
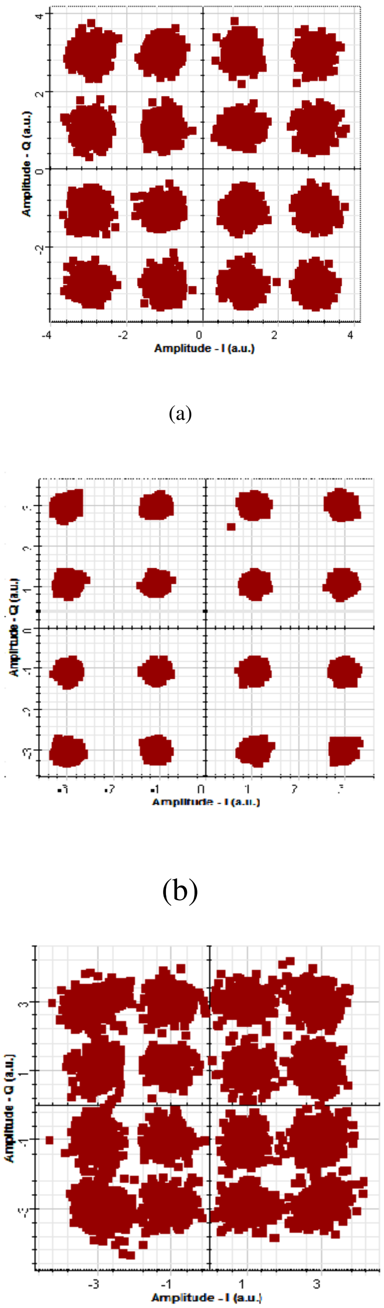


Fig.4 Electrical constellations observed before DSP at a power of 0.1 dB at 100 km.

Figure 5(a) shows distributions of the complex amplitude at 100 km transmission length obtained at input power of -10 dB. When the phase estimation is employed, the distribution of the amplitude is separated into four regions as shown in figure 5(a). The EVM value obtained for this sample is 12.4369 %. In figure 5(b) at a length of 110 km, distribution of amplitude is clearly separated and value of EVM is 5.2584%. In figure 5(c), differentially demodulating the same sample at a length of 130 km shows larger phase noise. Here, the EVM is maximum (16. 1359%)

The optical fiber propagation is classified into three different optical power transmission regions, namely, I) linear region, in which CD and PFC distortions are induced, II) intermixing region, where reduced distortion is achieved by the intera–ction between CD and PFC with SPM and SBS, and III) non linear region, which has



(a)

(b)

(c)

Fig. 5 Electrical constellations observed after DSP at a length of 100km for OLP of (a)-19 dBm(b)0.1 dBm (c)14 dBm

nonlinearity distortion from SP and SBS effect.

Figure 6 shows the EVM of DP 16 QAM systems at lengths of 100 km, 110 km, 120 km, 130 km and for back to back propagation. S(t) is varied in the range of -19 dBm to 14 dBm to analyze the optical power transmission regions. In region I, for the power range of S(t) < -8 dBm, the EVM decreases with increasing S(t) for all transmission distances. As P(t) increases, the signal to noise ratio (SNR) also increases, thus showing the linear relationship.

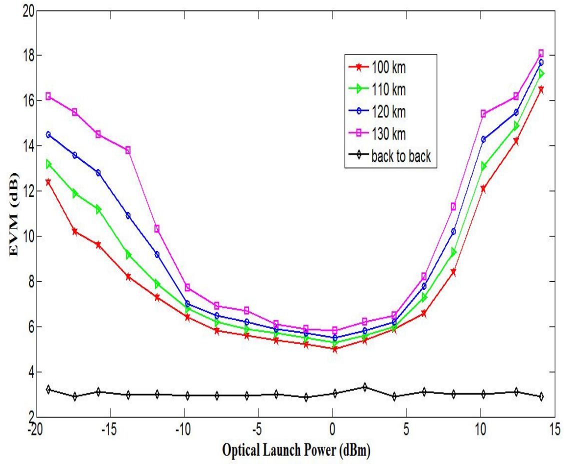


Fig.6 Graphical representation for EVM versus OLP for length = 100, 110,120,130 km and back to back.

This graphical representation is showing the same trend for all the transmission distances. At the lowest S(t) of -19 dBm for 100 km optical fiber length, the system experiences an EVM of 12.4369 %, whereas at 130 km, the EVM is 16.1359%. This shows that region I is highly distorted and do not perform optimally.

In the nonlinear region (III) for the OLP range of 4 dBm to 14 dBm, EVM increases with increase in S(t) for all the transmission spans mentioned. This is mainly due to the nonlinear phase distortion and the back reflection. At the launch power of 14 dBm for 100 km transmission, the EVM is 16.3125% and for 130-km length,the EVM is 18.1679%. The EVM in region (III) is higher than the region (I) because the nonlinear distortion will actuate in-band emission and increase the noise floor level.

In the intermixing region (II), for S(t) varying from -8 dBm to 4 dBm, it is experienced that as the transmission link increases, the intermixing region remains within this range. Our investigation show that impairments (whether linear or non linear) increase proportionally with the transmission span. In the region (II), average EVM at a length of 100-km is 5.5461% and at 130-km is 6.6783%. Thus, region I and III are not optimum due to the non linear propagation that induces in-band distortion. Hence, it is clear from the graphical representation that system performs optimally only in region II.

## Conclusion :

We have experimentally demonstrated 400 Gbps 16-QAM transmission system for analyzing the optical power limits during the nonlinear fiber propagation. Through simulations, we have found that for a power range -8 dBm to 4 dBm, this system performs optimally. The power range below -8 dB and greater than 4 dB shows a high value of EVM, indicating that large amount of noise and phase distortion is present. This analysis also showed that value of EVM increases with increase in length for a particular value of power. Hence, this paper specified that at the intermixing region optimal performance for the given system is obtained.

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