Analysis of Phase Noise and Gaussian Noise in terms of Average BER for DP 16-QAM Optical Coherent Receiver Using Digital Filters.

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Abstract - *The proposed paper utilized the concept of Coherent detection. A field received by advances in Digital Signal Processing (DSP), has renewed interest in optical communication systems with spectrally efficient modulation formats. Phase Noise and Gaussian Noise has been analyzed in terms of Average Bit Error Rate (BER) and Optical Signal to Noise Ratio (OSNR). OSNR component is used in order to introduce noise in the dual polarization Quadrature Amplitude Modulation (DP 16-QAM) optical coherent receiver system. The Noise is analyzed under the influence of different filters. Finally the best filter with best result have chosen in order to have minimum phase and Gaussian noise. To improve the performance of coherent receiver, a DSP algorithms like Constant Modulous Algorithm (CMA) and Blind phase search algorithm are used to compensate Propagation Mode Dispersion (PMD),Chromatic Dispersion (CD) and to achieve high data rate.*

Key Words: **Coherent detection, DSP, Average BER, DP 16-QAM,OSNR.**

1. INTRODUCTION

In today's era of high speed communication, dual polarization quadrature phase shift keying (DP-QPSK) and DP 16-QAM has proven itself a boon [1]. DP 16-QAM is a digital coherent reception technique, got popularity on advancement of Digital signal processing (DSP). Earlier, in 1990s, coherent receivers were using optical phase lock loop to track phase, which was difficult to achieve and dynamic polarization controller to align polarization of received signal with that of local oscillator, which was bulky and expensive [2]. In digital coherent receiver the above discussed two targets are achieved in electrical domain, which reduces the complexity and boosts the power of signal processing [3-4]. With the aid of EDFA (Erbium doped fiber amplifier) the optical communication has got a boom again. The receiver enhancement with the coherent detection and DSP have made it possible that one can transmit the data in the range of terabytes [5]. Polarization multiplexing and De-multiplexing is another way of increasing the bit rate. The DP QPSK has been demonstrated, with the view of increasing the transmission distance and bit rate the DP 16-QAM modulation format is taken. The transmission system is composed of five main parts i.e Transmitter, optical link, Receiver, DSP block, BER counting (BER TEST SET). The Noise analysis of the system is done by taking the OSNR component before the receiver block in order to introduce noise in the system apart from system noise. The noise analyzed before and after the carrier phase estimation is the Phase Noise and Gaussian Noise [10]. The Phase noise is due to interference of non-coherent frequency at the local oscillator stage.

2. DSP TECHNIQUES FOR DP 16-QAM

In order to recover the full complex field information in a very stable manner despite fluctuations in the carrier phase and signal State of Polarization. Fig. 1 shows the various DSP techniques discussed in the proposed paper.

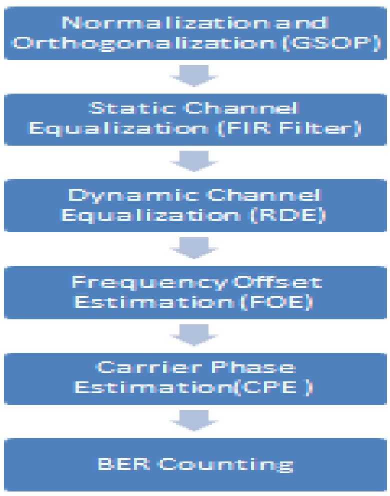

Fig -1: **Investigated DSP Techniques.**

2.1 Gram–Schmidt Orthogonalization Procedure

The Gram-Schmidt orthogonalization procedure (GSOP) [1] is used to correct for non-orthogonalization. Given two non-orthogonal components of the received signal, denoted by $r_I(t)$ and $r_Q(t)$, the GSOP results in a new pair of orthonormal signals, denoted by $I^o(t)$ and $Q^o(t)$, as follows:

$$I^o(t) = \frac{r_I(t)}{\sqrt{P_I}} \qquad (1)$$

$$Q'(t) = r_Q(t) - \frac{\rho r_I(t)}{\sqrt{P_I}} \qquad (2)$$

$$Q^o(t) = \frac{Q'(t)}{\sqrt{P_Q}} \qquad (3)$$

where $\rho = E\{r_I(t), r_Q(t)\}$ is the correlation coefficient, $P_I = E\{r^2_I(t)\}$, $PQ = E\{Q'^2(t)\}$, and $E\{\cdot\}$ denotes the ensemble average operator. The orthogonality for received signals with quadrature imbalance can be restored using (1)-(3) with the amplitudes of the recovered signals normalized.

2.2 Dispersion Compensation

Dispersion is the main factor in signal transmission damages in optical fiber. Without considering nonlinear, optical fiber can be seen as only one phase filter with the following transfer function:

$$G(z,w) = exp\left(-j\frac{D\lambda^2 z}{4\pi c}w^2\right) \qquad (4)$$

where z is the transmission distance, w is the angular frequency, j is the imaginary unit, λ is the channel wavelength, c is the speed of light, and $D = D_o + S \times (\lambda - \lambda_o)$ is the dispersion coefficient of the fiber for wavelength λ, S is the dispersion slope, and λ_o is the reference wavelength.

2.3 Compensation of Polarization Dependent Effects:

Polarization Mode Dispersion (PMD) is caused by the transmission light field of two orthogonal polarization that due to differential group delay. Compared with the dispersion, the loss caused by PMD is rapidly changing, which must use adaptive equalizer to compensate for such damage. According to the channel characteristics, the self-adaptive equalizer can dynamically adjust the digital filter coefficient so as to adapt to the change of channel. The impact of polarization dependent effects on the propagation of an optical signal is being modeled by the Jones matrix.

$$J = \begin{bmatrix} cos\theta e^{j\frac{\pi}{2}} & -sin\theta e^{-j\frac{\pi}{2}} \\ sin\theta e^{j\frac{\pi}{2}} & cos\theta e^{-j\frac{\pi}{2}} \end{bmatrix} \qquad (5)$$

To compensate for polarization rotation and PMD, a bank of 4 FIR filters modelled in terms of inverse Jones matrix arranged in a butterfly structure can be employed [2].While the CMA algorithm [4] is optimal for QPSK modulation format with a constant modulus, the residual error after blind equalization is sub-optimal for DP 16-QAM.

2.4 Frequency Offset Estimation (FOE)

The mixing with the local oscillator introduces a frequency and phase offset, leading to a rotating constellation diagram. The received signals are given by:

$$S(k) = C(k).e^{j.(2\pi\Delta f kT + \varphi_k)} + n(k) \qquad (6)$$

Where $\{C_k\}$ are data symbols, f is the carrier frequency offset that is to be estimated, φ_k is the carrier phase (which varies much slower compared to phase varying due to the frequency offset therefore at this step we can assume carrier phase is a constant value), T is the symbol period, and $\{n(k)\}$ are zero-mean Gaussian random variables.

For example for 16QAM the modulation information cannot be removed by 4th power. However, by following the CMA approach described in [8], $S^4(k)$ can be decomposed as:

$$S^4(k) = A.e^{j.4.(2\pi\Delta f kT + \varphi_k)} + e(k) \qquad (7)$$

$$A = E[C_k^4] \qquad (8)$$

where A is a constant amplitude and $e(k)$ is a zero mean process that can be viewed as a noise process.The frequency offset estimate based on the maximization of the periodogram (estimate of spectral density of a signal) of the $S^4(k)$ as shown below [9]:

$$S^4(k) = \frac{1}{4}\arg\{\max[|Z(f)|]\} \qquad (9)$$

$$Z(f) = \frac{1}{N}\sum_{k=0}^{N-1} S^4(k)e^{-j(2\pi k f T)} \qquad (10)$$

2.5 Carrier Phase Estimation

The blind phase search (BPS) algorithm [10] is used to recover and subsequently remove the remaining phase mismatch between the local oscillator and the signal.

The idea of the BPS algorithm is to try different test phases and find the optimum one. The received signal Z_k is rotated by B test carrier phase angles φ_b with:

$$\varphi_b = \frac{b}{B} \cdot \frac{\pi}{2} \quad \text{with } b \in \{0,1,2,\ldots B-1\} \quad (11)$$

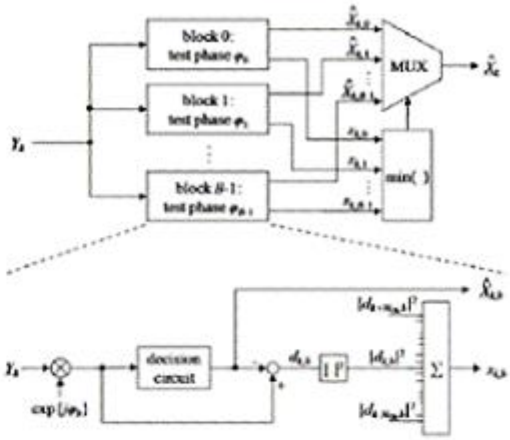

Fig -2: Blind Phase Search Algorithm

All rotated symbols are fed into a decision circuit and the squared distance $|d_{k,b}|^2$ to the closest constellation point is calculated in the complex plane:

$$\left|d_{k,b}\right|^2 = \left|Z_k e^{j\varphi_b} - \hat{X}_{k,b}\right|^2 \qquad (12)$$

Where $X_{k,b}$ is the decision of $Z_k e^{j\varphi_b}$.

3. SIMULATED RESULTS AND ANALYSIS

In the simulation, as shown in Fig. 1, 112 Gbps DP 16-QAM coherent receiver with DSP, using Optisystem simulator and MATLAB software has been designed, where main focus is on Average BER for different filter types with varying filter order of low pass filter.

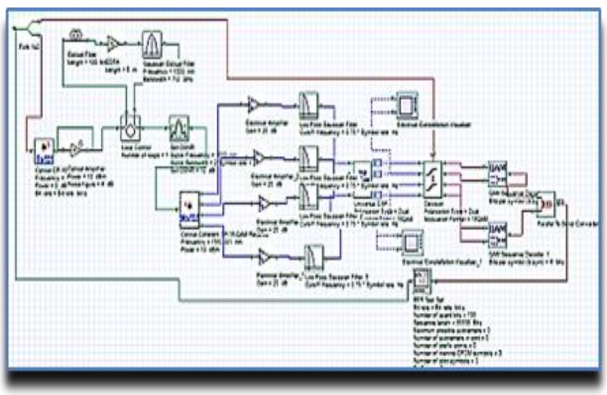

Fig -3: Block Diagram of 112 Gbps DP 16-QAM Coherent receiver.

In the proposed design sweep iterations has been used in the optical signal to noise ratio (OSNR) component and the BER TEST SET component. On using the feature of the simulator in order to make nested parameters, and thus obtaining the required average BER. With the higher order 16-QAM it is not easy to decide the filter to be used having minimum noise so graph have drawn between Average BER versus OSNR. The analysis is done in two steps firstly the graph is taken before carrier phase estimation (CPE) in order to analyse the Phase Noise. Secondly the noise analysed after (CPE) to analyse the required Gaussian Noise. Basically the Noise remaining in the system after all DSP stages is the Gaussian Noise. The required graph for phase noise in terms of average BER for different filter types with varying filter order are drawn in Fig.4 (a)-(d).

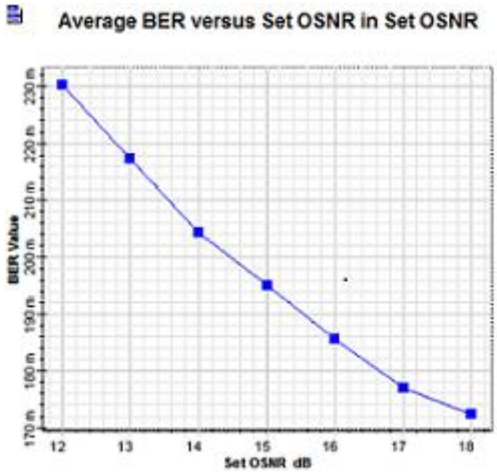

Fig. 4(a) Butterworth filter 4th order Before CPE

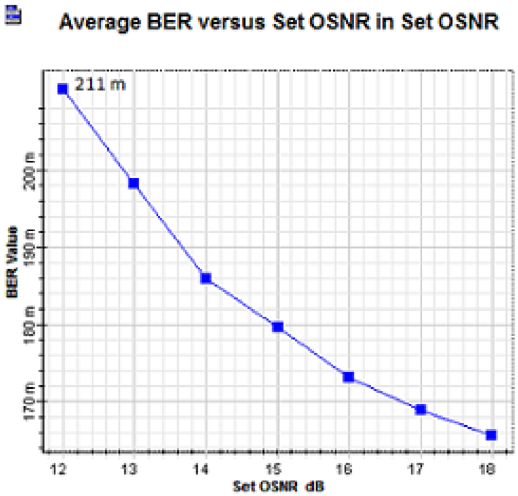

Fig. 4(b) Chebyshev filter 3rd order Before CPE

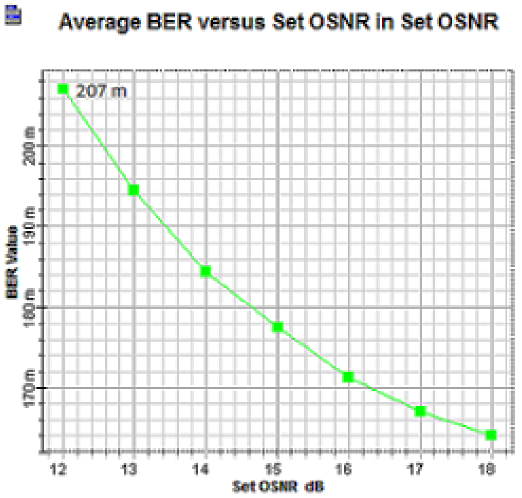

Fig. 4(c) Bessel filter 3rd order Before CPE

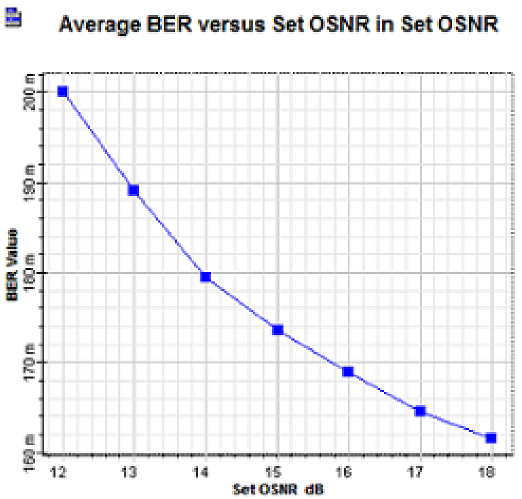

Fig. 4(d) Gaussian filter 3rd order Before CPE

Table I shows Phase noise in terms of Average BER for different filter types with varying filter order.

S.No.	Type	Order	Average BER
1.	Gaussian Filter	3rd	200 m
2.	Bessel Filter	3rd	207 m
3.	Chebyshev Filter	3rd	211 m
4.	Butterworth Filter	4th	230 m

The required graph for Gaussian Noise in terms of average BER for different filter types with varying filter order are drawn in Fig. 5(a)-(d).

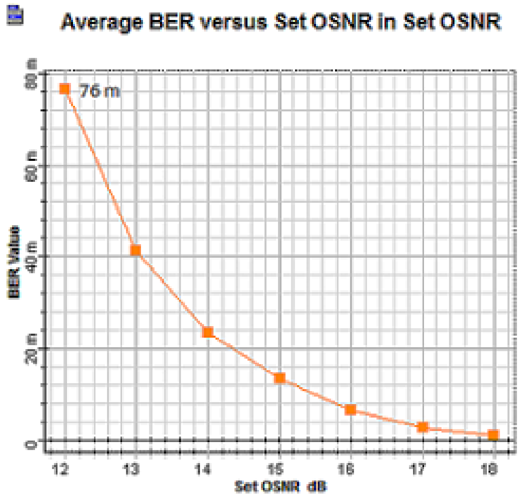

Fig. 5(a) Butterworth Filter 4th order After CPE

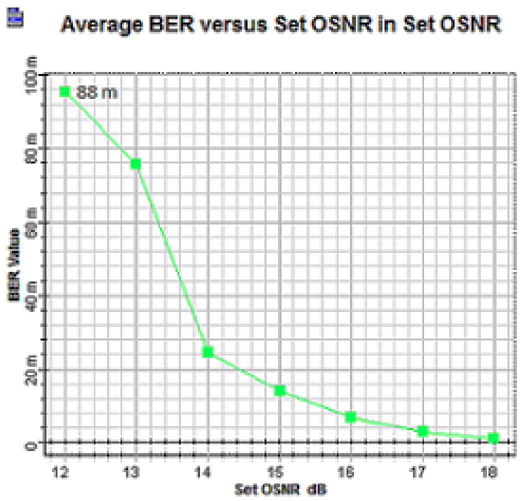

Fig. 5(b) Chebyshev Filter 3rd order After CPE

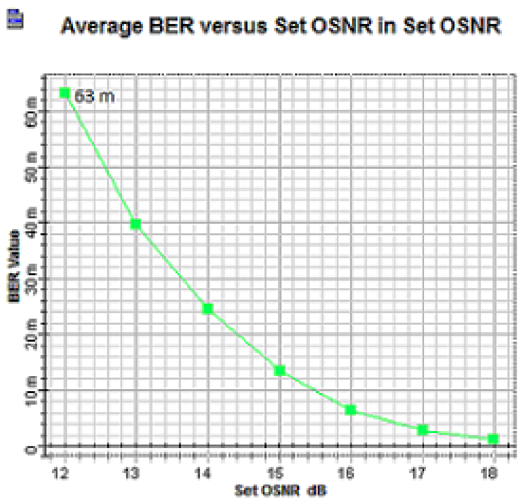

Fig. 5(c) Bessel Filter 3rd order After CPE

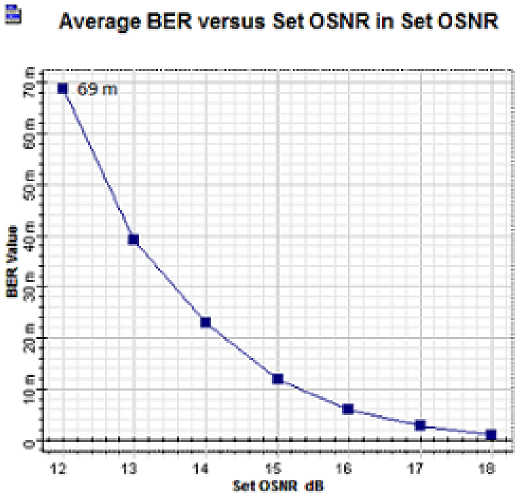

Fig. 5(d) Gaussian Filter 3rd order After CPE

Table II shows Gaussian noise in terms of Average BER for different filter types with varying filter order.

S.No.	Type	Order	Average BER
1.	Bessel Filter	3rd	63 m
2.	Gaussian Filter	3rd	69 m
3.	Butterworth Filter	4th	76 m
4.	Chebyshev Filter	3rd	88 m

4. CONCLUSION

Phase Noise and Gaussian Noise of DP 16-QAM optical coherent receiver has been analyzed under the influence of different digital filters, i.e. Bessel, Butterworth, Chebyshev and Gaussian filters by varying filter order from one to six. During analysis, Gaussian Filter 3rd order shows best result with minimum Average BER for the Phase Noise and Bessel filter 3rd order giving best result for the Gaussian Noise in terms of Average BER.

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