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Implementation of Memory Polynomial Based Adaptive Digital Post distortion for Coherent Optical System

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Abstract: The exponential growth in the ever –increasing demand of information require highly spectral efficient coherent optical systems with advanced modulation formats which allow the detection of in-phase and quadrature components of both polarizations and doubles the available capacity and spectral efficiency but the optical signal is severely degraded by linear and nonlinear transmission impairments after passing through the fiber. We have designed and implemented adaptive digital post distortion model to reduce fiber nonlinear impairments using memory polynomial for single channel DP-16QAM coherent system.
Keywords: Digital Post distortion DPost-D, DP-16QAM, Memory polynomial, Coherent system, ACPR

I. INTRODUCTION

Due to the limitation of transmission bandwidth and the exponential growth in the demand of network traffic, mobile applications, internet video services , there is a strong requirement of the employment of highly spectral efficient coherent systems with advanced modulation formats such as Dual polarization quaternary phase shift keying (DP-QPSK) and Dual polarization 16 quadrature amplitude modulation (DP—16QAM) which reduces the cost per bit and increase transmission capacity for high data rate signals. Higher optical signal to noise ratio (OSNR) is required with advanced modulation formats for long haul transmission system for achieving given bit error rate(BER)which requires more signal launch power in the fiber but increased launch power degrades signal quality due to kerr nonlinear effects that limits the achievable transmission distance in single channel and WDM systems [1-8].As compensation of linear effects is possible , research is boosted for compensation of nonlinear impairments which limit the transmission performance of the system. Number of techniques in optical domain and digital domain are proposed for compensation of fiber nonlinear impairments. Some of the compensation methods include electronic equalization , digital back propagation(DBP) , optical phase conjugation(OPC) ,frequency referenced transmission , phase conjugated twin waves ,spectral conversion [9-10]perturbation based nonlinear mitigation [11-12]. One of the prominent fiber transmission impairment compensation method for the coherent optical systems is the use of Digital Back-propagation (DBP) algorithm . Split step fourier transform and Volterra series nonlinear equalizer techniques based on digital back propagation have been used for fiber non linearity compensation. Main drawback of these techniques is the high complexity requirement in practical implementation due to large number of iterations. [13].Various investigations have been done to minimize the complexity requirement [14-16] .Algorithms based on DSP with DBP-SSFM and DBP-VSNE have been investigated to reduce the complexity for fiber nonlinear impairment compensation. In spite of these investigations there are number of models developed in wireless communication which can be investigated in the optical systems to further reduce the complexity. Among these models, Memory Polynomial algorithm is one of the best solution which give a good trade-off between complexity and performance. Memory polynomial model is used as pre distortor in radio over Fiber link . Pre distortion technique is based on the principle that a it generates inverse nonlinear characteristics of the received signal and produces an overall system that compensates the nonlinear impairments . These inverse characteristics are introduced into the input of the system thereby cancels the nonlinear impairments of the system. Various pre distortion models are used for compensation [17-18]. The Volterra model [19], Wiener model [20], Parallel-Wiener model [21], Wiener–Hammerstein model [22], memory polynomial Model (MPM) [23], envelop memory polynomial model (EMPM)[24] are proposed for pre distorter model. The memory effect play very important role to design a pre distorter. In this paper adaptive digital post distortion DPost-D technique for the compensation of fiber nonlinearities in coherent optical systems is implemented with memory polynomial model

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II. MEMORY POLYNOMIAL MODEL FOR DPOSTD

Nonlinear systems with memory are mainly modeled by the Volterra series [25]but its main disadvantage is the implementation complexity which increases with the increase in the nonlinearity order and memory depth [26] Volterra series consisting of multidimensional convolution describing a nonlinear system with memory can be written as[27]

$$v(n)\sum_{k=1}^{k} v_k(n)$$

$$\text{Where } v_k(n) = \sum_{k=1}^{K}\sum_{l_i=0}^{M}\sum_{l_p}^{M} h_p(l_1, l_2 \dots\dots l_p)\prod_{m=1}^{k} u(n-l_n)$$

is a k dimensional convolution of the input with volterra kernel h_p. $u(n-l_n)$ is the delayed version of the input signal u(n) by $l_n$samples,V(n) are the samples of the output signal, $h_p(l_1, l_2 \dots\dots l_p)$ represents the pth order volterra kernels of the system, highest nonlinear order of the system is K. Memory polynomial is a truncation of volterra series which considers only diagonal kernelsless is complex as compared to volterra series which can be used to model DPost-D and fiber system. The coefficients of memory polynomial are estimated using least square criterion. Memory polynomial expression for the output is formulated as

$$y(n) = \sum_{k=1}^{K-1}\sum_{l=0}^{L-1} c_{k,l}x(n-l)|x(n-l)|^k$$

Where $x(n-l)$ and y(n) are the complex baseband input and output signals, $c_{k,l}$ are the polynomial co-efficients,L is the memory length and K is the nonlinearity order [28-29]. One of the main advantage of the Memory polynomial (MP) model is that beside providing the co-efficients in the linear form,they can be estimated by least square estimation algorithms with complexity of MP developlinearity with K and M.

III. EXPERIMENTAL SETUP DESCRIPTION

To validate the proposed memory polynomial digital post distortion (DPostD) model ,simulation of 112Gb/s single channel DP-16QAM transmission system was done using optisystem .. The narrow bandwidth 0.1MHz continuous wave laser operating at 193.1THz at different powers is modulated byMach Zehnder Modulator(MZM) to generate dual polarization 16quadrature amplitude modulation (DP-16QAM)signal which is amplified by an amplifier of gain16 dB and noise figure 4 dB .The signal is passed through a transmission link consisting of SSMF of 80km was characterized by attenuation 0.2dB/Km , dispersion coefficient of 16ps/nm-km, effective area 80μm^2 , nonlinear coefficient of and EDFA (erbium doped fiber amplifier) with gain 16dB and noise figure 4dB to compensate attenuation through the fiber. The received optical signal is post processed in MATLAB. After the transmission through the fiber,, the signal is filtered using 2nd order Gaussian filter with bandwidth of 50GHz and then received at the receiver by phase and polarization diverse coherent receiver and passed through the ADC(Analog to digital converter)for digital signals. The digitized signal is processed by a set of digital signal processing algorithms. Order of polynomial (K)and memory length(Q) are the key parameters that decide how well the DPostD model works.

IV. RESULTS AND DISCUSSIONS

Memory polynomial is one of the simplest forms which can correct both the nonlinearities and the memory effects. In this section, the performance of the adaptive algorithm is demonstrated. The optical fiber link is modeled. For the extraction of DPD coefficients, several techniques are available in the indirect learning architecture, such as least square (LS), least mean squares (LMS), recursive least squares (RLS). Out of these techniques, the least squares algorithm is most straightforward as compared to the other two. So to obtain the model coefficients, Least square estimation with PSO algorithm has been used. For validation of proposed modeling technique, optical fiber link data at input and output has been taken. To model DPost-D using memory polynomial , different combinations of order of polynomial (K) and memory length (Q) are considered to find the optimal combination. Training length of 200000 has been taken. The nonlinearity behavior and accuracy of fiber model and DPost-D can be effectively shown by power spectral density . Power spectral density of optical fiber link input, optical fiber link output without D-PostD, modeled fiber link and optical fiber link output with D-PostD is shown in the fig. 1 and 2 Simulations has been done with Matlab 2014 to implement the memory polynomial equation and to verify the proposed D-PostD to suppress the nonlinearities of an optical fiber link. Table 1 shows the ACPR values for different combinations of order of polynomial (K)and memory length(Q) .The ACPR values at the input of fiber link and modeled fiber and D-PostD with Q =1 and K=3 are shown in the table 2. The characteristics of the transmission system changes due to the presence of the optical fiber which introduce AM/AM characteristics of power0dbm

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From the Table1 it is concluded that the best compensation of fiber non linearities is obtained with Q=1 and K=3 as the error is minimum for this combination i.e. 0.0113. The memory length of 1 and polynomial degree of 3 is sufficient for modeling of optical fiber link. By keeping memory length same i.e 1 with increase in polynomial degree or keeping polynomial degree same i.e. 3 with increase in memory length, increases the error. The ACPR values of actual fiber link, modeled fiber link and modeled DPost-D for =1 and K=3 are shown in the Table2. Due to high ACPR improvement capability adaptive digital Dpost-D can be used for compensation of fiber nonlinearities.

TABLE I
ACPR measurement for different memory length and polynomial degree

Memory length(Q)	Polynomial degree(K	LowerACPR2	LowerACPR1	Upper ACPR 1	UpperACPR2	Error
1	3	-2.0392	-2.4502	-1.4171	-6.6565	0.0113
1	5	0.3794	2.9799	0.5948	-3.1511	0.0207
2	3	-2.3822	-2.5038	-1.3134	-6.4241	0.0116
2	5	3.3759	7.6404	2.1984	1.6638	0.0171

TABLE II
ACPR measurement for modeled fiber and DPost-D(in dB)

Parameter	Actual fiber	Modeled fiber	D-PostD Modeled
LowerACPR2	-3.4708	-2.0392	9.1403
LowerACPR1	-3.6285	-2.4502	11.0411
Upper ACPR 1	-2.7073	-1.4171	10.962
UpperACPR2	-8.0892	-6.6565	12.7291

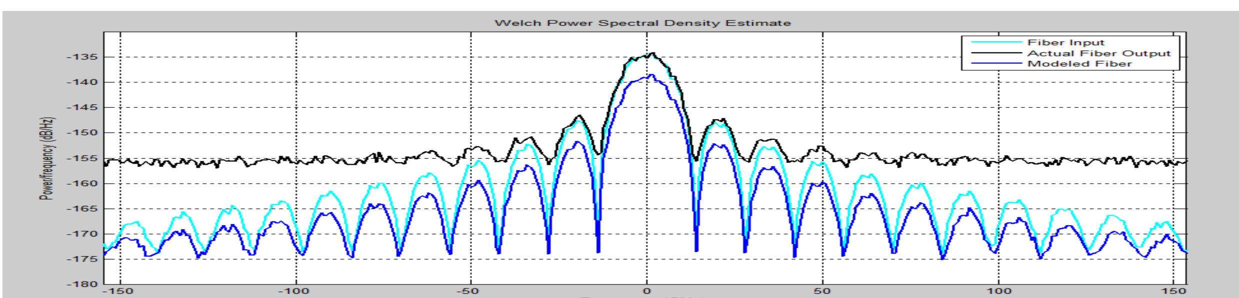

Fig.1 Power spectral densityfor modeled fiber link

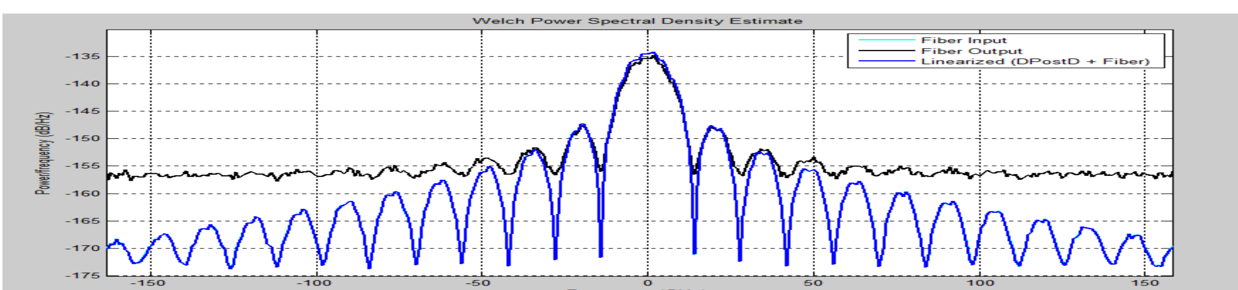

Fig.2 Power Spectral Density for modeled D-PostD

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V. CONCLUSION

This paper proposed the memory Polynomial modeling of optical fiber link for different combinations of memory length and polynomial order which can enhance the modeling accuracy . Simulation results were analyzed and it was observed that the memory length 1 and polynomial order 3 is sufficient to model the optical fiber link. Due to ease of implementation and high ACPR improvement capability, adaptive D-PostD (Digital Post Distortion) is one of the approach that can be used tof compensation of optical fiber link nonlinearities.

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