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Study of Equalization Enhanced Phase Noise in EDFA-Amplified Optical Communication Systems

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Abstract— The significant influence of equalization enhanced phase noise on the performance of long-haul EDFA-amplified optical fiber communication systems has been investigated in this paper. A 128-Gbaud DP-16QAM multi-channel 2400 km Nyquist-spaced optical transmission system has been considered, with the application of the electronic dispersion compensation and the digital nonlinearity compensation schemes.

Keywords— Optical fiber communication; Equalization enhanced phase noise; Analytical mode

I. INTRODUCTION

The increasing demand for the data capacity poses high requirements on the quality of signals transmitted in fibers and the suppression of transmission impairments [1]–[4]. However, the interaction between the chromatic dispersion (CD) and the laser phase noise (LPN), also called equalization enhanced phase noise (EEPN) [5]–[7], can be hardly compensated using digital signal processing (DSP), and severely degrades the performance of optical communications.

In this paper, the EEPN effect is studied in the 128-Gbaud dual-polarization 16-ary quadrature amplitude modulation (DP-16QAM) Nyquist-spaced multi-channel optical transmission system, with electronic dispersion compensation (EDC) and digital nonlinearity compensation (NLC), based on numerical simulations and the Gaussian noise (GN) model [8]–[10].

Under EDC and NLC, the effective signal-to-noise ratio (SNR) of a Nyquist-spaced multi-channel optical system, influenced by the EEPN, can be expressed as [7]–[9]

\[ \text{SNR}_{\text{EDC}} = \frac{P}{P_{\text{ASE}} + P_{\text{NL}} + \sigma_{\text{EEP}}^2 \cdot P} \]  \hspace{1cm} (1)

\[ \text{SNR}_{\text{NLC}} = \frac{P}{P_{\text{ASE}} + P_{\text{Signal-ASE}} + \sigma_{\text{EEP}}^2 \cdot P + P_{\text{Signal-EEP}}} \]  \hspace{1cm} (2)

where $P$ donates the launch power of signals, $P_{\text{ASE}}$ represents the ASE noise generated in the erbium-doped optical fiber amplifier (EDFA), $P_{\text{NL}}$ is the signal-signal interference from the nonlinear Kerr effect, $\sigma_{\text{EEP}}^2$ is the variance of the EEPN, $P_{\text{Signal-ASE}}$ is the signal-ASE interaction, and $P_{\text{Signal-EEP}}$ is the interaction between signals and EEPN [7], [8].

III. TRANSMISSION SETUP

To explore the impact of the EEPN in EDFA-amplified long-haul wavelength division multiplexing (WDM) optical fiber communication system, numerical simulations have been carried out with a system setup shown in Fig. 1. A 128-GHz spaced laser comb was employed as the transmitter laser source. Data sequences in all channels are random and independent. Split-step Fourier simulations based on the Manakov equation [11], [12] are performed for the transmission link with standard single mode fibers (SSMFs). The local oscillator (LO) laser with linewidths of 0 Hz and 100 kHz is operated in the coherent

Fig. 1 Schematic of DP-16QAM Nyquist-spaced multi-channel long-haul optical fiber communication system using EDC and NLC. NPS: Nyquist pulse shaping; PBS: polarization beam splitter; PBC: polarization beam combiner.
detection. The EDC employs a frequency domain equalizer [13], and the NLC uses the reverse split-step Fourier solution of the Manakov equation [14]. An ideal carrier phase estimation (CPE) [15] is applied to fully compensate the laser phase noise. Polarization mode dispersion (PMD) [16] and laser frequency offset are neglected. Detailed parameters can be found in Table I.

![Table II: System Parameters](image)

**IV. Results and Discussions**

Fig. 2 shows the central channel performance as a function of the signal launch power per channel in the single-channel 128-Gbaud DP-16QAM 2400 km optical transmission system. Solid and dotted lines represent analytical results for NLC and EDC cases, respectively, and markers denote simulation results. A high consistency can be observed between model results and simulations, which validates the accuracy of the GN-EEPN model. It is found that the peak SNR in the system is degraded due to EEPN by over 4 dB, in the case of NLC. Such obvious degradation reveals the vital deterioration, originating from the EEPN, in the long-haul optical systems, especially for signals transmitted at a relatively high data rate. Similar phenomena can be observed in Fig. 3, where theoretical and simulation results of the 128-Gbaud DP-16QAM 5-channel Nyquist-spaced 2400 km optical transmission are presented. The accuracy of the model and the great performance degradation accounting for the EEPN are also demonstrated in the multi-channel transmission system.

**V. Conclusions**

In this work, the impact of EEPN is investigated in the 128-Gbaud DP-16QAM multi-channel Nyquist-spaced long-haul optical transmission system. The significant degradation of the system performance due to EEPN has been demonstrated. This paper provides an in-depth insight into the design of long-haul high data rate multi-channel coherent optical transmission systems, which will be one of the major constructions in the next-generation telecommunication infrastructure.

![Fig. 2: The SNR of the central channel as a function of the launch power per channel in the 128-Gbaud DP-16QAM single-channel 2400 km optical transmission system.](image)

![Fig. 3: The SNR of the central channel as a function of the launch power per channel in the 128-Gbaud DP-16QAM 5-channel Nyquist-spaced 2400 km optical transmission system.](image)

**References**