Simplified Volterra series based nonlinear equalization for IM/DD Systems

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ABSTRACT

The frequency chirp of Direct modulation laser (DML) introduces nonlinear interference to the signal, and traditional linear equalizers such as FFE cannot handle nonlinear noise and perform poorly, so nonlinear equalizers are needed to process it. This paper proposes a new simplified Volterra nonlinear equalizer (VNLE) method for the chirp characteristics of DML systems-S-VNLE. We experimentally use AWG to generate 64Gb/s PAM4 signals on a 1550nm DML, and use a nonlinear equalizer VNLE, DP-VNLE, S-VNLE, and linear equalizer FFE at the receiver, results showed that S-VNLE had the highest sensitivity improvement of 0.5dB compared to DP-VNLE, with the same complexity as DP-VNLE and a 50% reduction compared to VNLE.

Keywords: direct modulation laser, volterra nonlinear equalizer, PAM4

1. INTRODUCTION

The development of the information age has led to an increasing demand for internet speed, especially within digital centers. Due to the need for fiber optic transmission networks in digital centers, cost and space are the primary considerations [1]. Compared to coherent communication, direct modulation systems based on intensity modulation have lower costs, and in direct modulation systems, DML has the lowest cost and footprint [2-5]. But compared to Machzend modulator (MZM) and Electric absorption modulation laser(EML), the frequency chirp of DML causes greater nonlinear interference to the signal [6-8]. In order to eliminate the nonlinear noise caused by DML, a recovery algorithm must be adopted at the receiver end. Although the commonly used restoration algorithm FFE has a simple structure, its linear structure cannot handle nonlinear noise, VNLE naturally has the ability to cope with nonlinear noise due to its nonlinear structure. However, the nonlinear structure of VNLE also brings greater computational complexity, which is difficult to bear in practical applications, so it is necessary to simplify VNLE. The existing simplification based on VNLE includes simplified VNLE based on diagonal construction (DP-VNLE), as well as preprocessing based on system characteristics [9-14].

In this paper we proposes a new simplified VNLE method for DML systems. When the adiabatic chirp of DML is added to the fiber dispersion, it creates a second-order beat term between the signal and its time integration. The second-order nonlinear distortion caused by adiabatic chirping leads to the coefficients of some cross terms being regularly smaller. We reset the cross-beat terms to zero and simplified the second-order Volterra equalizer, resulting in what is known as S-VNLE. In the experimental verification, we utilize 1550nm DML to generate 64Gb/s PAM4 signals, and use linear equalization algorithm FFE and nonlinear equalization algorithm VNLE at the receiving end, respectively, DP-VNLE, S-Simplified VNLE based on system characteristics, analyzing the balancing ability of different algorithms for nonlinear crosstalk caused by DML, The second-order complexity of S-VNLE is reduced by 50% compared to DP-VNLE, just like DP-VNLE. The performance of S-VNLE is superior to DP-VNLE, and the transmission experiment results show that the sensitivity can be increased by up to 0.5dB.

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2. EXPERIMENTAL SETUP AND RESULTS

The experimental structure is shown in Figure 1. At the transmitter, raw information is generated through a pseudo-random bit sequence in Matlab and mapped onto PAM4. The signal rate is 64Gbit/s, which is then pulse formed and upsampled to match with AWG and then input into AWG to generate the original electrical signal. DML converts electrical signals into optical signals, with a 3dB bandwidth of 15GHz. The optical signal is transmitted through optical fibers and amplified. At the receiver, it is received by a photodetector, VOA is mainly used to adjust the size of the received optical power. The oscilloscope is used to collect received electrical signals, with a sampling rate of 80GSa/s, and digital signal processing adopts offline processing.

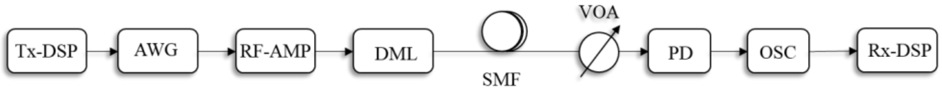

Figure 1. Experimental setup.

Collect experimental data and process it on the Matlab platform. Firstly, resampling of the oscilloscope sampling rate and AWG transmission rate, as well as matching filtering corresponding to the receiver, is carried out to obtain data that is fed into the equalizer for processing linear and nonlinear damage. Equalizers are also divided into linear equalizer-FFE and nonlinear equalizer-VNLE, DP-VNLE， S-VNLE。 After the signal is processed by the equalizer, it will be judged and the error rate will be calculated to evaluate the ability of different algorithms to deal with nonlinear damage.

The algorithm processing result is shown in Figure 2, where the number of taps in FFE is 51, The first order part of VNLE, which is the linear part, has a consistent number of taps with FFE, while the second order nonlinear part has 13 taps. Simplified VNLE and VNLE remain consistent. Try to maintain a consistent number of taps in the algorithm to achieve control variables.

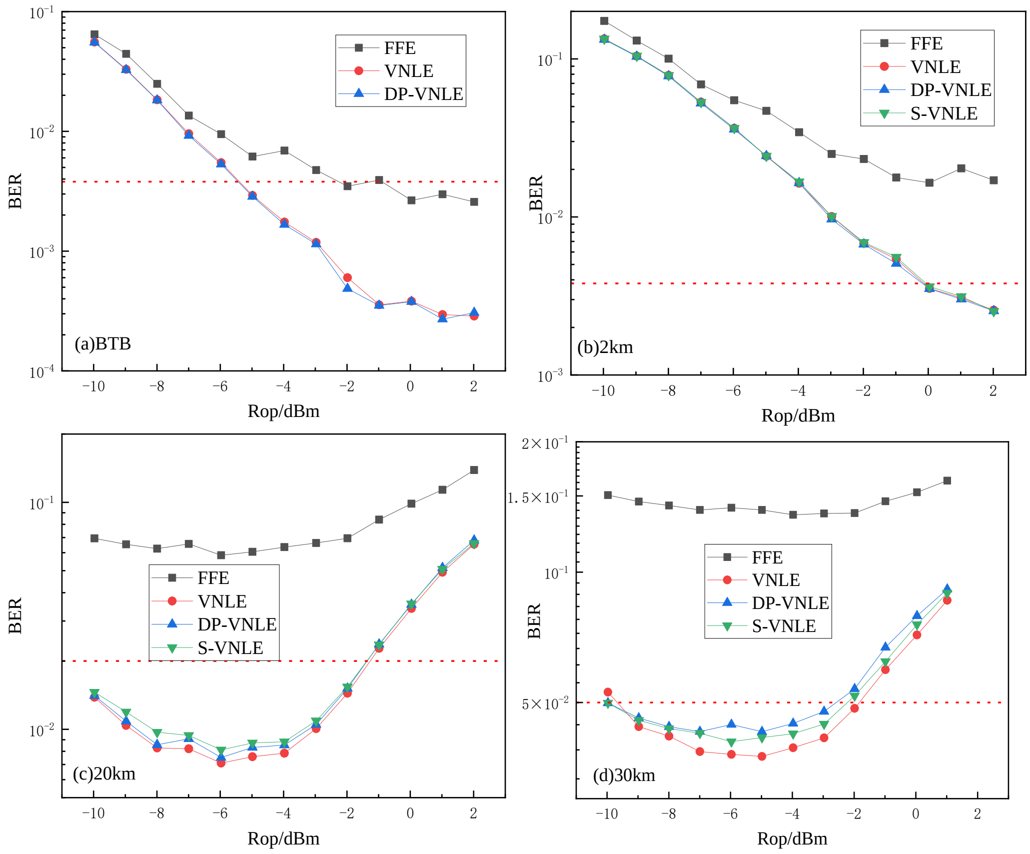

Figure 2. BER at different distances (a) 0, (b) 2, (c) 20, and (d) 30-km.

It is worth noting that the PD detector used in the experiment is designed for OOK, so receiving high-power PAM4 signals will result in performance degradation and an increase in bit error rate. Figure 2 shows the final BER comparison of different algorithms at BTB (Back to Back), 2km, 20km, and 30km. For Figure 2a, the performance of the nonlinear equalizer is similar, while the performance of the linear equalizer FFE is poor. This is because in the BTB scenario, The chirp characteristic of DML itself causes nonlinear distortion of the signal, while FFE is a linear equalizer that cannot handle nonlinear damage well. For 2km, 20km, and 30km, it can be seen that VNLE's performance is far superior to FFE, which is consistent with the previous analysis. The performance of DP-VNLE and S-VNLE is slightly worse than that of VNLE, and S-VNLE performs better. At a transmission distance of 30km, Under the same BER conditions, S-VNLE can increase the sensitivity of the receiver by up to 0.5dB. This demonstrates the superior ability of VNLE to handle nonlinear noise caused by DML. Similarly, the S-VNLE proposed in this paper performs slightly better than DP-VNLE in the same complexity as DP-VNLE.

Figure 3 shows a comparison of the complexity of the second-order terms of VNLE, DP-VNLE, and S-VNLE nonlinear equalization algorithms. It can be clearly seen that VNLE has the highest complexity, with a second-order computational complexity of up to 91, while DP-VNLE and S-VNLE have a second-order complexity of 46, reducing complexity by about 50%. The cost of complexity reduction is the loss of performance. For DP-VNLE, the relative decrease in reception sensitivity is more than 1dB, while for S-VNLE, the maximum decrease does not exceed 0.5dB. This indicates that S-VNLE performs better than DP-VNLE in terms of complexity similar to DP-VNLE

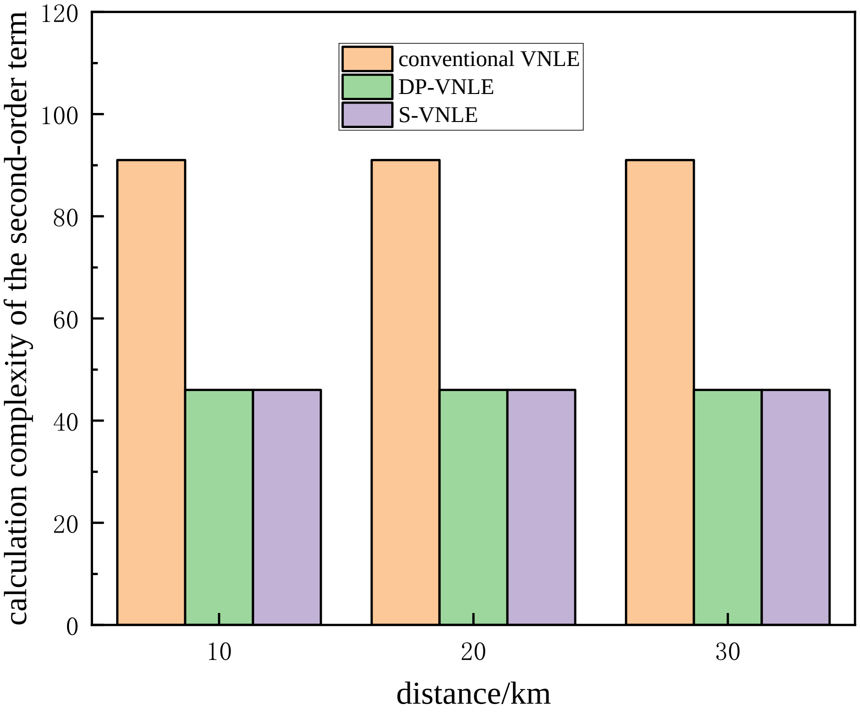

Figure 3. Second-order calculation complexity of three algorithms at different distances.

3. CONCLUSIONS

In this paper, we apply different equalization algorithms to deal with signal nonlinear damage caused by adiabatic chirp in DML systems, and verify it with a 64Gbit/s PAM4 actual experimental system. We propose a new simplified VNLE method - S-VNLE which distinguishes it from DP-VNLE. The data processing results show that the second-order complexity of S-VNLE is reduced by 50% compared to DP-VNLE, and its performance is superior to DP-VNLE. The transmission experiment results show that the sensitivity can be increased by up to 0.5dB.

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