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An Efficient Hybrid Equalizer for 50 Gb/s PAM-4 Signal Transmission Over 50 km SSMF in a 10-GHz DML-Based IM/DD system

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Abstract: We experimentally demonstrate an effective hybrid equalizer with FFE and truncated Volterra filter for a 50-Gb/s PAM-4 over 50-km SSMF in a DML-based IM/DD system. The results show significant computational complexity savings without performance degradation.

OCIS codes: (060.4510) Optical communications, (060.2330) Fiber optics communications

1. Introduction

Driven by the rapid development of broadband services, the ever increasing bandwidth requirement of short-reach optical interconnection grows even faster than that in backbone networks [1]. Since the short-reach optical systems are more sensitive to the cost and energy consumption, the intensity modulation and direct detection (IM/DD) system is preferred for short reach applications. Meantime, several advanced modulation formats have been used to fulfill the requirement of low cost and high capacity. In general, PAM-4 is more suitable due to its simpler architecture and lower power consumption [2]. However, IM/DD system suffers from strong inter-symbol-interference (ISI) associated with the limited bandwidth, and nonlinear distortions resulted from the chromatic dispersion [3]. Volterra filter is an effective equalizer to deal with the nonlinear distortions. However, it cannot effectively mitigate the ISI because the first order of the Volterra filter does not take the backward symbols interference into consideration. Feed forward equalization (FFE) can shorten the channel impulse response and also shape the signal and noise [3], which can effectively compensate for the ISI and reduce the complexity of the following equalization. Moreover, the Volterra filter can be pruned to reduce the computational complexity [4].

In this paper, we propose and experimentally demonstrate an effective hybrid equalizer, which is a combination of FFE and truncated Volterra filter, for a 50-Gb/s PAM-4 signal transmission over 50-km SSMF in a 10-GHz DML-based IM/DD system. At the receiver equalization stage, the FFE followed by higher order terms of Volterra filter construct the hybrid equalizer to compensate the ISI and nonlinear distortion. Considering the enormous computational complexity of the Volterra filter even with the moderate memory length, we use a truncated Volterra filter, which retains parts of kernels with strong correlation and truncates the kernels with a marginal contribution, to alleviate the complexity issue. The experimental results show that BER is close to floor when the pruned number is larger than 4 which leads to a significant computational complexity savings under similar transmission performance.

2. The Hybrid Equalizer

The received *n*-th sample after the Hybrid equalizer can be expressed as,

$$\begin{aligned} y(\mathrm{n}) = h_0 &+ \sum_{m_1=-(\mathrm{L}_1-1)/2}^{m_1=(L_1-1)/2} h_1(\mathrm{m}_1)x(\mathrm{n}-\mathrm{m}_1) \\ &+ \sum_{m_1=0}^{L_2-1}\sum_{m_2=m_1}^{L_2-1} h_2(\mathrm{m}_1,\mathrm{m}_2)\prod_{j=1}^{2} x(\mathrm{n}-\mathrm{m}_j) \\ &+ \sum_{m_1=0}^{L_3-1}\sum_{m_2=m_1}^{L_3-1}\sum_{m_3=m_2}^{L_3-1} h_3(\mathrm{m}_1,\mathrm{m}_2,\mathrm{m}_3)\prod_{j=1}^{3} x(\mathrm{n}-\mathrm{m}_j) \end{aligned} \tag{1}$$

where $x(\mathrm{n}-\mathrm{m})$ is the *(n-m)*$^{\mathrm{th}}$ sample of the received signal, $h_k(\mathrm{m}_1,\mathrm{m}_2,\ldots,\mathrm{m}_k)$ is the Volterra kernel of the k^{th} order and L is the system memory length. The Volterra kernels can be optimized by Recursive Least Square (RLS) algorithm. The total tap numbers of the hybrid equalizer is the same as the traditional Volterra : $L_1 + L_2 \times (L_2+1)/2 + L_3 \times (L_3+1) \times (L_3+2)/6$. Similarly, the computational complexity increases faster with larger number of 2nd- and 3rd- order memory lengths. To alleviate the complexity issues inherently introduced by the Volterra processing, we truncate the product terms of samples which are more than P_n interval for higher order terms, where P_n is the reserved number and defined as pruned number.

3. Experimental Results

The experimental setup is shown in Fig. 1. A pseudo-random bit sequence (PRBS) with 2^{15}-1 in length is used for bit-to-symbol mapping and the PAM-4 signal generation. Considering the limited bandwidth of transceiver, the generated PAM-4 signal is applied to a 101-tap root-raised cosine filter with the roll-off factor of 0.25 for pulse shaping to relax the bandwidth requirement of electrical components and sampling rate of DAC/ADC. Then, the PAM-4 signal is uploaded into an arbitrary waveform generator (AWG, Tektronix®AWG70001A) with a 25-GS/s sample rate and 8-bit resolution. After electrical amplification, the output signal directly modulates the DML. The DML employed in this experiment is a low-cost and commercial 10 GHz component with the output power of 5.5 dBm and wavelength of 1537 nm. A variable optical attenuator (VOA) is applied to fix the received optical power at -6 dBm after transmitting through 25 km and 50 km SSMF, respectively. After the SSMF transmission, the PAM-4 signal is direct-detected by a PD with bandwidth of 10 GHz without any inline optical amplifier or pre-amplifier. The electrical PAM-4 signal is first sampled by a Tektronix oscillator scope (DPO73304D) operating at 50 GS/s and then processed offline. The radio frequency (RF) spectrum of PAM-4 signal with the root-raised cosine filter after 50 km transmission is also shown in the inset of Fig. 1. The RF spectrum has a sharp roll-off after 10 GHz.

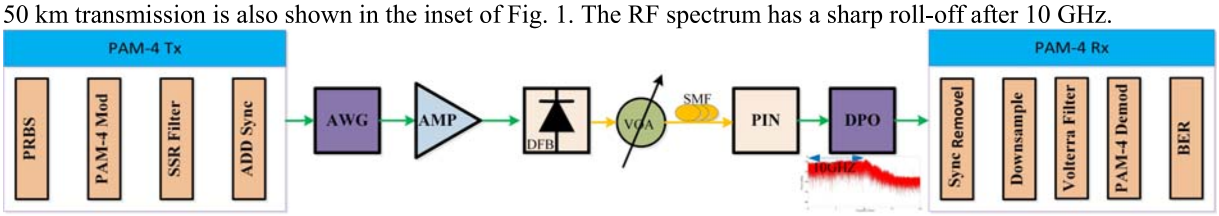

Fig.1 Experiment setup

Fig.2 shows the BER performance with Volterra filter and the hybrid equalizer with full sized counterpart under different transmission distances. The memory lengths are the same as (71, 20, 5) in the two cases. As shown in Fig. 2, the BER performance with the hybrid equalizer is below 7 % FEC and increases by an order of magnitude compared with the traditional Volterra filter. Since the bandwidth of the transceiver is still smaller than the signal bandwidth even with Nyquist pulse shaping, the ISI limits the transmission performance. The Volterra filter cannot effectively mitigate the ISI because the first order of the Volterra filter does not take the backward symbols interference into consideration. The ISI limitation effect is alleviated with hybrid equalizer, which takes both the interference of forward and the backward symbols into consideration. From Eq. (1), the hybrid equalizer has similar computational complexity as traditional Volterra filter, which is unacceptable for implementation. Due to the strong ISI, we only truncate the 2nd- and 3rd- order of the hybrid equalizer, which has greater contribution to calculation complexity. Fig. 3 depicts the tap numbers and BER performance with different pruned numbers after 50 km SSMF transmission. The computational complexity has a strong relationship with the number of pruned taps. There is a tradeoff between the BER performance and the pruned numbers. As shown in Fig. 4, the BER performance closes to BER floor when the pruned number is larger than 4. The BER is 4.7×10^{-3} and the tap number is 275 at pruned number of 4, which exhibits a good balance between the complexity and the performance.

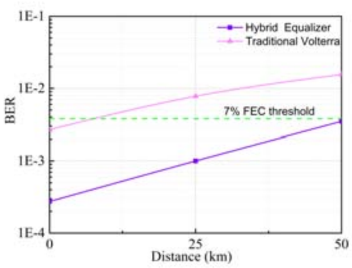

Fig.2 BER performance versus transmission distance

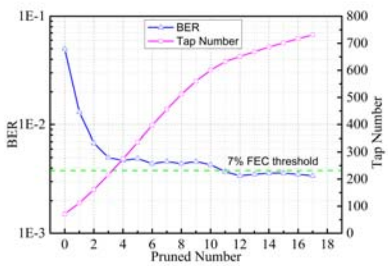

Fig. 3 Tap numbers and BER under different pruned number

4. References

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