Noise-resistant all-optical sampling based on a temporal integrator

Zihan Geng,[1,2] Deming Kong,[1,2,*] Bill Corcoran,[1,2] Arthur James Lowery[1,2]

[1]*Electro-Photonics Laboratory, Electrical and Computer Systems Engineering, Monash University, Clayton, VIC3800, Australia*
[2]*Centre for Ultrahigh-bandwidth Devices for Optical Systems (CUDOS), Monash University, Clayton, VIC3800, Australia*
**Corresponding author: deming.kong@monash.edu*

Abstract: We propose a novel noise-resistant all-optical sampling with temporal integration. A proof-of-concept experiment shows a receiver sensitivity improvement up to 8-dB for a 1.25 Gbaud PAM 4 signal.© 2018 The Author(s)

OCIS codes: (060.2330) Fiber optics communications; (060.4080) Modulation; (060.4370) Nonlinear optics fibers.

1. Introduction

Optical sampling is a promising signal processing technique that has been applied in various applications such as optical time division de-multiplexing [1, 2], waveform measurements [3], and eye diagram measurements [4]. Recently, we have expanded these application to arbitrary relocation of signal frequencies [5], and to mitigate electrical bandwidth limitations of direct detection receivers (DD) [6]. However, optical sampling is usually vulnerable to the signal noise. The sampling proceses also samples noise, both in-band and out-of-band [7]. Although conventional optical filters can be applied to reduce the out-of-band noise, the achievable minimum bandwidth is limited, and precise optical frequency alignment is needed. Optical sampling with a noise suppression capability is therefore desired to improve the quality of the sampled signal.

Recently, we have proposed a cross-phase modulation (XPM) based temporal integrator as an all-optical digital-to-analog converter (DAC) [8]. In this work, taking advantage of a precise self-tracking optical filtering function from the temporal integrator, an all-optical sampling scheme with strong out-of-band noise suppression is proposed. Up to 8-dB receiver sensitivity improvement is observed for a 1.25 Gbaud PAM 4 signal.

2. Principle and experimental Setup

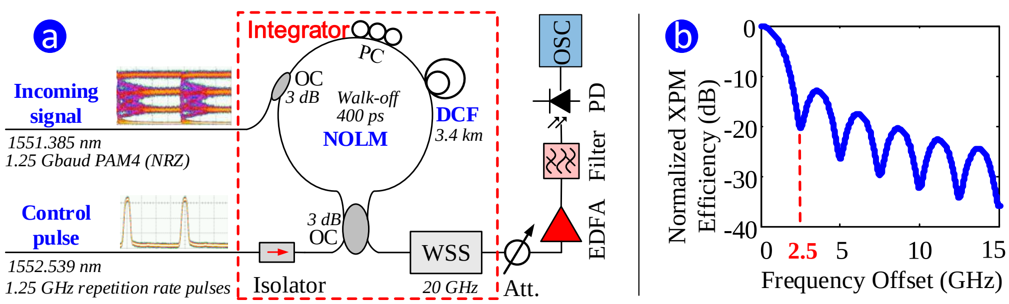

Fig. 1. (a) Experimental setup of noise-resistant optical sampling of 1.25 GBaud PAM 4 signal; OC: optical coupler; PC: polarization controller; Att.: attenuator; PD: photo-diode; OSC: oscilloscope. (b) XPM efficiency with 400 ps integration time.

Fig. 1 (a) shows a proof-of-concept experiment setup of optical sampling based on a temporal integrator in a nonlinear optical loop mirror (NOLM). There are two inputs of the temporal integrator, an incoming signal and a control pulse [9]. Fig. 1 (b) shows the XPM efficiency against the frequency offset from the center of the incoming signal. By introducing the 400 ps walk-off with respect to the control pulse, the sampling stage provides a 2.5 GHz sinc-shaped effective optical filtering function. The bandwidth of the filter can in principle be easily tuned by altering the integration time, either by changing the frequency separation between the signal and control pulse, or changing the nonlinear medium (here, a DCF).

In this experiment, the incoming signal is a 1.25-Gbaud non-return-to-zero (NRZ) PAM 4 signal centered at 1551.385 nm, and the control pulse is an optical pulse train centered at 1552.539 nm with 100-ps pulse-width and 1.25-GHz repetition. A 3.4-km DCF with a dispersion of -107.4 ps/nm/km and a dispersion slope of -0.3567 ps/nm^2/km (@1566 nm) is inserted in the NOLM as the nonlinear medium. The control pulse is phase-modulated by the incoming signal in the NOLM with a designed 400-ps temporal integration window and is then phase-to-amplitude converted at the output port of the NOLM. The modulated control pulse (i.e., sampled signal) is extracted by a 20-GHz Gaussian filter and then detected by an optical preamplifier receiver at 3 dBm received optical power. The receiver is composed of an EDFA, a 100-GHz wide optical band-pass filter (OBPF), and a 70-GHz bandwidth photodiode. The internal post-detection anti-aliasing filter in the 40 GSa/s real-time sampling oscilloscope (OSC) is set to either 2-GHz or 10-GHz. Since the transitions of the incoming signal will corrupt the desired phase modulation within the NOLM [8], the temporal integrator is designed to integrate over the 400-ps flat portion of each symbol.

3. Results and discussions

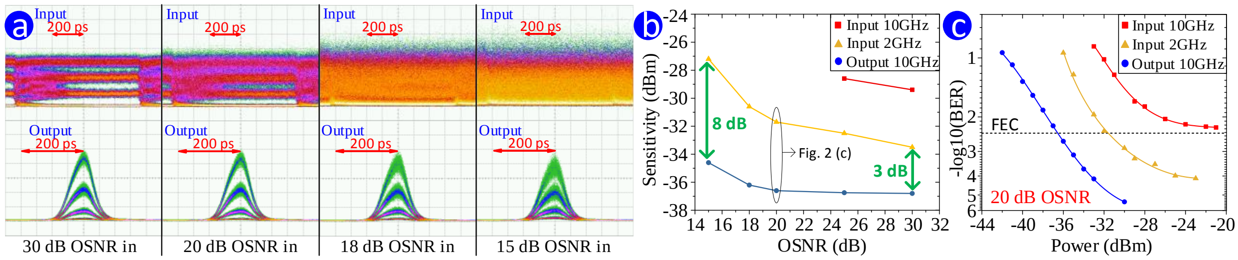

Fig. 2. (a) Eye diagrams of the received signal with 10-GHz anti-aliasing filter and the output of NOLM with 10-GHz anti-aliasing filter under OSNRs of 30 dB, 20 dB, 18 dB and 15 dB. (b) Sensitivity versus OSNR plot (c) BER versus received optical power plot with incoming signal OSNR set to 20-dB, either directly detected with a 2- or 10-GHz anti-aliasing filter, or after NOLM sampling with a 10-GHz anti-aliasing filter.

Fig. 2 (a) shows eye-diagrams of the incoming signal and NOLM outputs, with an anti-aliasing filter set to 10-GHz. Qualitatively comparing the incoming signals and corresponding NOLM outputs under different OSNRs, there is a clear noise suppression effect. In Fig. 2 (b) and (c), the performance of the directly received signal with a 2-GHz (yellow), or a 10-GHz filter (red), and the output of the NOLM with 10-GHz filter (blue) are compared under different OSNRs. The 2-GHz and 10-GHz filters are implemented by a digitally defined anti-aliasing filter in the OSC, and are chosen to reflect receiver bandwidths that are either much greater than, or approaching the signal bandwidth. The directly received signal is compared with the proposed 2.5-GHz integrator when filtering the 1.25-Gbaud signal. Note that the anti-aliasing filter can only be set to integer numbers in GHz bandwidth.

Fig. 2 (b) shows sensitivity versus OSNR. Compared with 2-GHz anti-alias-filtered incoming signal, the proposed temporal integrator improves sensitivity by 3, 5 and 8 dB at OSNRs of 30, 25, and 15 dB, respectively. The sensitivity improvement comes from NRZ-to-RZ conversion, since RZ signal has relatively higher peak power, and from the effective optical filtering function of the NOLM suppressing noise-noise beat upon photo-detection compared to the 20-GHz WSS filter. The noise-noise beat is worse at lower OSNRs, as reflected in Fig. 2 (b). This noise suppression has a stronger impact when comparing with a 10-GHz anti-alias-filtered incoming signal, were the proposed temporal integrator improves the receiver sensitivity by 7 and 8 dB at OSNRs of 30 and 25 dB. At OSNRs $\leq$ 20 dB, the BERs of 10-GHz filtered incoming signal are all above 3.8×10^{-3} FEC limit, so receiver sensitivity is undefined. Fig. 2 (c) shows received optical power versus BER with incoming signal OSNR set at 20 dB. The NOLM output appears to tend toward an error floor at lower BER than the directly received incoming signal.

4. Conclusions

In conclusion, we have experimentally demonstrated a novel noise resistant optical sampling method with a temporal integrator, allowing a narrow band optical filter function before the optical receiver. Up to 8-dB receiver sensitivity improvement has been observed compared with a 2-GHz anti-aliasing filter for a 1.25 Gbaud PAM 4 signal. The proposed scheme can be scaled for high speed operation by simply changing the integration time.

Acknowledgments

Supported by the ARC's Centre of Excellence (CE110001018) and Laureate Fellowship (FL130100041) schemes.

References

[1] M. Nakazawa, T. Yamamoto and K. R. Tamura, Electronics Lett. **36,** 2027-2029 (2000).
[2] T. Richter, E. Palushani, C. Schmidt-Langhorst, et al., J. Lightwave Technol. **30,** 504–511 (2012).
[3] T. Kanada and D. L. Franzen, Optics Lett. **11,** 4–6 (1986).
[4] H. Takara, S. Kawanishi, A. Yokoo, et al., Electronics Lett. **32,** 2256–2258 (1996).
[5] Z. Geng, C. Zhu, B. Corcoran, et al., in Asia Communications and Photonics Conference (ACP, 2016), pp. AF3B.2.
[6] Z. Geng, B. Corcoran, A. Boes, et al., in Optical Fiber Communications Conference and Exhibition (OFC, 2017), pp. M2J.6.
[7] J. Li, M. Westlund, H. Sunnerud, et al., IEEE Photon. Technol. Lett. **16,** 566-568 (2004).
[8] D. Kong, Z. Geng, B. Foo, et al., Opt. Lett., **42**(21), 4549 (2017).
[9] J.P. Sokoloff, P.R. Prucnal, I. Glesk, et al, IEEE Photon. Technol. Lett. **5,** 787-790 (1993).

130.194.20.173 {ts '2019-06-20 23:18:16'}