160 Gb/s 256QAM Transmission in a 25 GHz Grid Using Kramers-Kronig Detection

Yingjun Zhou[1,3], Jianjun Yu[2,*], Yiran Wei[1], Rui Deng[3], Li Zhao[1,3], Nan Chi[1], Gee-Kung Chang[3], and Yun Zhang[4]
[1]*Key Laboratory for Information Science of Electromagnetic Waves (MoE), Department of Communication Science and Engineering, Fudan University, No. 220, Handan Road, Shanghai, China*
[2]*ZTE (TX) Inc., Morristown, New Jersey 07960, USA* [4]*ZTE Corp. Beijing, China*
[3]*School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332, USA*
**Email: yu.jianjun@ztetx.com*

Abstract: We experimentally demonstrated a 20 Gbaud 256QAM over 20 km of SSMF in a 25 GHz grid employing Kramers-Kronig scheme to reconstruct optical phase. To the best of our knowledge, this is the first time that 256QAM format is implemented in a Kramers-Kronig single-sideband direct detection system.
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1. Introduction

The rapid traffic growth in metro networks requires high-capacity and low-cost optical transceivers supporting more than 100 Gb/s per channel transmission. Compared with coherent detection, direct detection (DD) is preferred due to its lower power consumption and lower system complexity [1-2]. Applying single-sideband (SSB) modulation in DD systems can effectively mitigate the power fading caused by chromatic dispersion. However, it still suffers from signal-signal beat interference (SSBI) induced by square-law detection [3]. Recently, the Kramers-Kronig (KK) scheme is proposed in [4] to reconstruct the optical phase of the transmitted signal from its photo-detected amplitude which can suppress the SSBI penalty with the minimum phase condition.

Nowadays, many experiment results based on SSB KK in DD systems are reported confirming its capability to overcome SSBI. To further increase the spectral efficiency, high order QAM format is investigated in SSB KK transmissions. In [5], four WDM channels of 28 GBaud 64QAM signal is successfully transmitted over 80 km of SSMF with 35 GHz channel spacing. A 30 Gbaud 64 QAM transmission over 125 km of SSMF using a DFB laser is reported in [6]. However, there is no higher than 64QAM format experimental demonstration based on KK SSB systems till now.

In this paper, we further explore the KK scheme performance with higher order QAM format and narrow channel spacing. We experimentally demonstrate 20 Gbaud 128QAM (140 Gb/s) and 256QAM (160 Gb/s) SSB KK transmissions in a 25 GHz grid over 20 km of SSMF which achieves high data rate per channel beyond 100Gb/s under 25GHz bandwidth limitation. To the best of our knowledge, this is the first time that 256QAM format is implemented based on KK detection.

2. Principle and Experiment Setup

Fig.1(a) shows the experimental setup. The transmitted signal is generated by an offline Matlab program as shown in Fig.1(b). The 20 Gbaud 128/256QAM signals are upsampled by a factor of 4 to satisfy the broadened bandwidth due to square-root and logarithm operation in KK detection. The SSB signals are generated by a root-raised-cosine (RRC) pulse shaping filter with a 0.01 roll-off factor and up-converted to an intermediate carrier frequency of 10.2 GHz. Then, digital pre-equalization is performed.

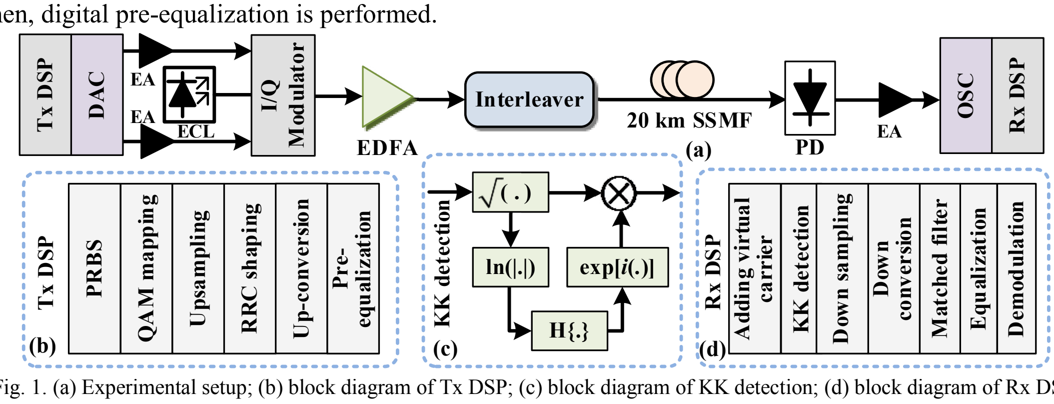

Fig. 1. (a) Experimental setup; (b) block diagram of Tx DSP; (c) block diagram of KK detection; (d) block diagram of Rx DSP

The real and imaginary parts of the transmitted signal are loaded into two ends of an 80 GSa/s DAC with 20GHz bandwidth respectively. The DAC output signals are then amplified by two electrical amplifiers (EA) with 32 GHz bandwidth and 20dB gain to drive the 30GHz bandwidth IQ modulator. The bias of the IQ modulator is set around the quadrature point. An ECL generates the continuous wave light with line width ~100 kHz at 1552.3 nm. An Erbium-doped fiber amplifier (EDFA) is added before the 25GHz interleaver. This interleaver is used to simulate a WDM channel in 25GHz grid. The spectra of the optical SSB signal with and without the interleaver is shown in Fig. 2(a). After 20 km SSMF transmission, the signal is detected by a 50 GHz photo detector (PD) and amplified by an EA. An 80 GSa/s digital real-time oscilloscope with 33 GHz electrical bandwidth is used to sample the signal.

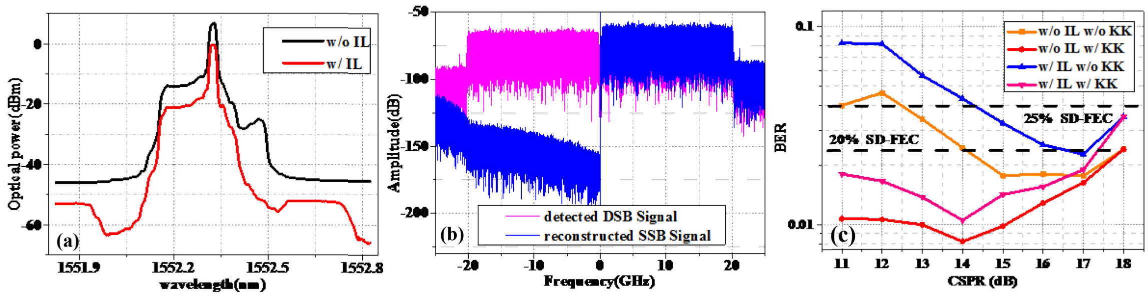

Fig. 2. (a) spectra of the optical SSB Signal w/o and w/ 25GHz interleaver; (b)detected DSB and reconstructed SSB signal after KK detection; (c) BER versus CSPR w/o, w/ KK detection, w/o and w/ the interleaver (the interleaver is represented as IL in the figures)

The receiver side DSP is shown in Fig. 1(d). Duo to the use of AC-coupled PD which is simpler and cheaper than a DC-coupled PD, the DC component of the detected signal is almost zero. Thus the signal is firstly added by a positive value to act as the virtual carrier constructing the minimum phase signal for KK detection which can be expressed as [7]

$$V_{DC}(n) = \beta \times |V_D(n)| + V_D(n) \tag{1}$$

where $V_D(n)$ is the detected signal amplitude, β is the factor to make sure $V_{DC}(n)$ meets the minimum phase condition which should be larger than 1, $V_{DC}(n)$ is the signal with virtual carrier. The phase of the signal is reconstructed with the KK receiver shown in Fig. 1(b) and can be expressed as,

$$\varphi(n) = H\left\{\ln\left|\sqrt{V_{DC}(n)}\right|\right\} \tag{2}$$

where $H\{.\}$ stands for the Hilbert Transform. Thus the reconstructed SSB signal $V_{KK}(n)$ after KK detection can be represented as,

$$V_{KK}(n) = \sqrt{V_{DC}(n)} \times e^{j\varphi(n)} \tag{3}$$

The spectra of the detected DSB and reconstructed SSB signals are shown in Fig. 2(b) which clearly validates that the complex-valued SSB signal can be reconstructed with KK detection. After down sampling, down conversion, filtering, post-equalization and demodulation, BER can be finally calculated.

3. Results and Discussion

Firstly, the influence of the 25 GHz interleaver is tested with and without KK detection using 1 dBm received optical power and 128QAM format as shown in Fig. 2(c). CSPR values from 11dB to 18dB are controlled by changing the bias point of the IQ modulator and fixing the signal power before loading into the IQ modulator. The system performance becomes worse due to the limited bandwidth caused by the interleaver.

The system performance applying 128QAM is shown in Fig. 3. The received optical power is adjusted through an optical attenuator to find the optimum received power. In the back-to-back (btb) case, BER versus CSPR with 2, 1, 0 and -2 dBm received optical power with KK detection is measured in Fig. 3(a). The results of variation trend for 2 dBm are different from the other three duo to the saturation effect in the system. When the received power is increased from -2 dBm to 1 dBm, the system performance improves with KK detection because of the increasing SNR. But when the received power is continually increasing to 2dBm, the system performance is impaired by the saturation effect when CSPR is lower than 15dB. When CSPR is larger than 15dB, the effective signal power is decreasing with the fixed total received power and increasing carrier power. Thus the system is no longer restricted by the saturation effect. At this time, ASE noise is the main limitation instead of SSBI. Thus even with higher power and no saturation, using KK detection can’t achieve more improvement. Therefore the received power for KK detection is set as 1dBm for 20 km SSMF transmission. Fig. 3(b) shows the BER versus CSPR with and without KK detection in two cases. At the optimum CSPR of 14dB and optimum received optical power of 1dBm, BER is decreased from 0.024 to 0.008 in the btb case and 0.057 to 0.011 over 20 km of SSMF in a 25GHz grid which is under the 20% SD-FEC threshold. The system performance is limited by the SSBI at lower CSPR, thus applying KK detection works better. However, the improvement of KK detection decreases as CSPR further increases because the system performance is limited by the ASE noise with higher CSPR. The optimum CSPR for the system without KK is about 3 dB higher than the system using KK. Thus a 140 Gbit/s 128QAM transmission (net data rate 117 Gbit/s) over 20 km of SSMF in a 25GHz grid with KK scheme is implemented.

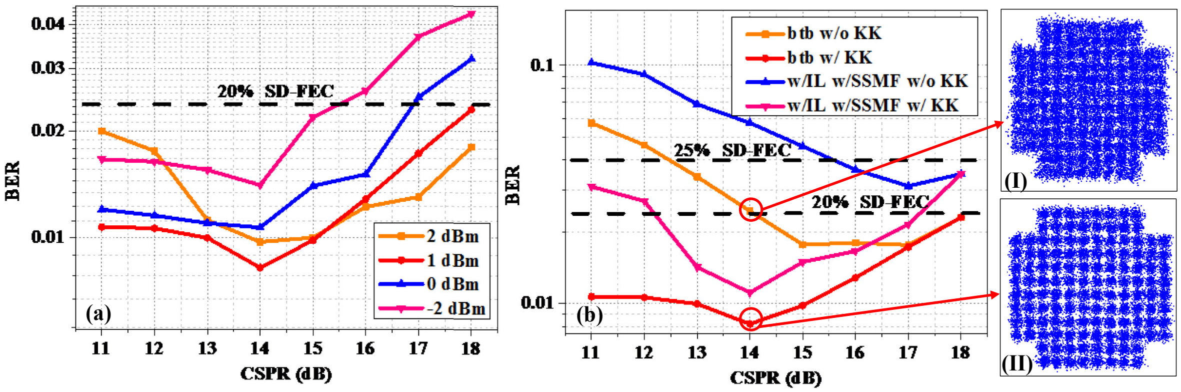

Fig. 3. 128QAM system performance: (a) BER versus CSPR with different received optical power with KK detection in btb case; (b) BER versus CSPR w/o and w/ KK detection; Insets: received constellations (I) w/o and (II) w/ KK detection

The system performance applying 256QAM is further evaluated as shown in Fig. 4. The BER performance in the btb case is also tested at first to find the optimum received optical power for the best KK performance. In the btb case, BER without KK detection is 0.063 at 1 dBm received power which is above the 25% SD-FEC threshold of 0.04. But after KK detection, BER is decreased to 0.032. After 20 km of SSMF in a 25 GHz grid, BER is decreased from 0.090 to 0.037 which is under the 25% SD-FEC threshold of 0.04 with the optimum CSPR of 14 dB and 1 dBm received power. Thus a 160 Gbit/s 256QAM transmission (net data rate 128 Gbit/s) over 20 km of SSMF in a 25GHz grid with KK scheme is implemented.

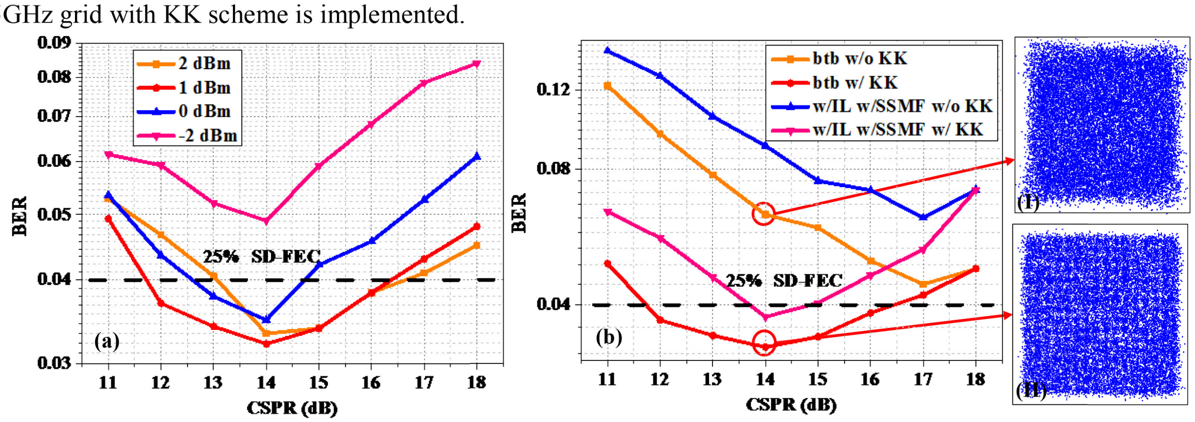

Fig.4. 256QAM system performance: (a) BER versus CSPR with different received optical power with KK detection in btb case; (b) BER versus CSPR w/o and w/ KK detection; Insets: received constellations (I) w/o and (II) w/ KK detection

4. Conclusions

We evaluate the system performance of high order modulation format applying KK scheme. 140 Gbit/s (net data rate 117 Gbit/s) 128QAM and 160 Gbit/s (net data rate 128 Gbit/s) 256QAM over 20 km of SSMF in a 25 GHz grid based on KK SSB direct detection transmissions are experimentally demonstrated. To the best of our knowledge, this is the first time 256QAM format is applied in a KK SSB based DD system under 25 GHz bandwidth limitation which shows the potential to achieve 4-λ 100 Gb/s WDM optical interconnect.

5. References

[1] J. C. Rasmussen, et al., in Proc. of ECOC 2014, pp 1-3.
[2] S. Randel, et al., in JSTQE, 16(5):1280-1289 (2010).
[3] Y. Zhang, et al., Opt. Express 18(16), 16751–16764 (2010).
[4] A. Mecozzi,et al., Optica 3(11), 1220–1227 (2016).
[5] Z Li, et al., in Proc. of ECOC 2017,Tu2E.1.
[6] K. Schuh, et al., in Proc. of ECOC 2018, Tu3G.4.
[7] Zhu M, et al., in Proc. of OFC 2018, M2C.5.