Optical Amplification-Free 200 Gbaud On-Off Keying Link for Intra-Data Center Communications

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Abstract: We demonstrate a 200 Gbaud OOK link without any optical amplification using C-band externally modulated laser with 3.3 dBm of modulated output power. We achieve below 6.25% overhead HD-FEC threshold after 200 meters of SMF. © 2022 The Author(s)

1. Introduction

The ever-growing internet traffic demands are setting highly challenging requirements for the high-performance computing (HPC) and the intra-Data Center links. Scaling the Data Center capacity to 1.6 Tbps/link in an economically viable way is the key [1]. Moreover, we need to support low latency requirement for high-speed computing. Multilevel pulse amplitude modulation (PAM) can be used to increase the capacity for bandwidth limited components but sets stringent requirements in terms of linearity and noise tolerance for driving electronics and photonics. Therefore, it is worth reviving interest in on-off keying (OOK) for this type of short-reach application. For instance, a thin-film lithium niobate Mach Zehnder modulator seems to be a viable option for a transmitter having low driving voltage and high bandwidth at the expense of an external laser [2-4]. A plasmonic modulator with a high-speed 2:1 selector has been used to achieve 222 Gbaud OOK transmission over a 120 meters single-mode fiber (SMF), yet the setup included two erbium-doped fiber amplifiers (EDFA) [5], which increases the power consumption. The earlier demonstration shows a 204 Gbaud OOK transmission over inter-Data Center distances using the C-band externally modulated laser (EML) and optical dispersion compensation [6]. The same transmitter was also used for 180 Gbaud OOK transmission over intra-data center distance using an EDFA [7].

In this paper, we demonstrate a 200 Gbaud OOK link without any optical amplification using the C-band EML with 3.3 dBm of modulated output power. We achieve below 6.25% overhead (OH) hard-decision forward error (HD-FEC) threshold of 4.5×10^{-3} after 200 meters of single-mode fiber using only decision feedback equalizer (DFE) with 33 feed-forward taps (FFT) and 3 feedback taps (FBT). That enables low latency requirement for high-speed computing. The link configuration also supports 112 Gbaud PAM4 and 100 Gbaud PAM6 transmission.

2. Experimental setup

The experimental setup is shown in Fig.1. We generate the signal in MATLAB using the developed digital signal processing (DSP) routines. We use a random binary sequence of >1 million bit-length obtained using the Mersenne Twister generator with a shuffled seed number. Next, the sequence is up-sampled and filtered with a root-raised-cosine (RRC) filter having a 0.01 roll-off factor after optimization. Frequency domain pre-equalization up to 70GHz is used to compensate for bandwidth limitation in the system. The link response is shown in Fig.1(b). Please observe that the response of the end-to-end system calibration of the optical link follows closely the calibration with just the Arbitrary Waveform Generator (AWG). We load the pre-compensated signal into the 256 GSa/s M8199A AWG. The output of the AWG is connected to an electrical amplifier (22 dB gain, 60 GHz bandwidth). We need to compensate for high-frequency roll-off and have enough driving voltage to enhance the extinction ratio of the modulated signal. A C-band externally modulated laser is used at an optical transmitter that consists of a monolithically integrated distributed feedback laser and traveling-wave electroabsorption modulator (DFB-TWEAM) [8]. At the output, we obtain 3.3 dBm of modulated optical power at 17 degrees Celsius when the TWEAM is biased at minus 1.6 volts and the DFB is driven by 120 mA of current. The signal was transmitted over

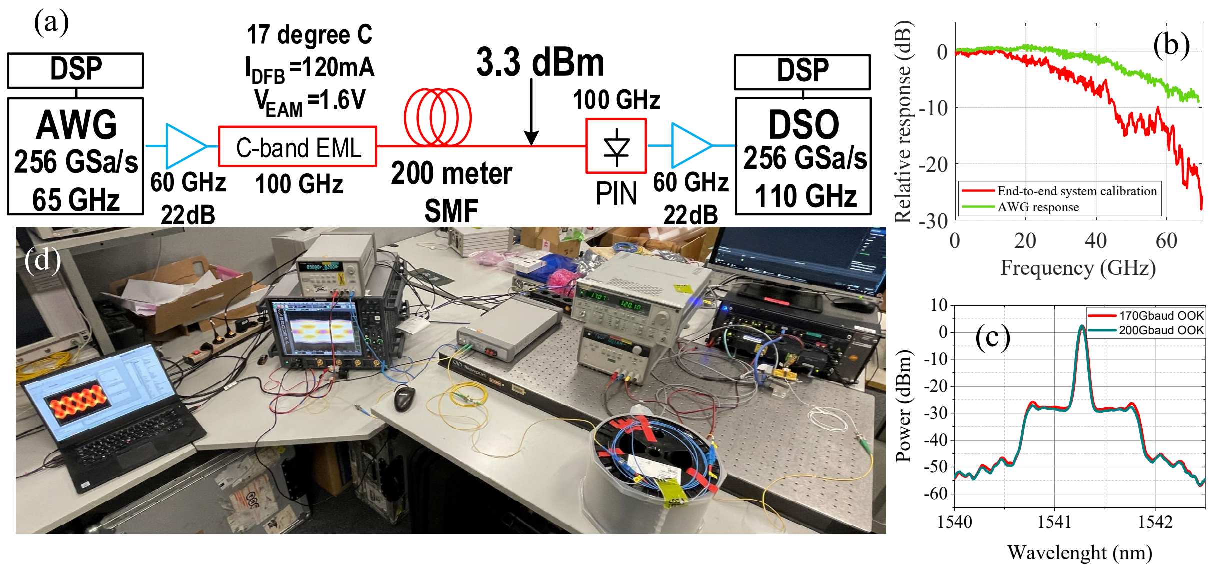

Fig. 1. (a) Experiment setup, (b) end-to-end system calibration with Keysight IQtools, (c) optical spectrum at 0.1nm resolution, and (d) setup picture.

200 meters of SMF. The dispersion tolerance at the operation wavelength (see the modulated signal optical spectrum in Fig.1(c)) limits the achievable transmission distance. At the input of the PIN photodetector (3 dB BW >90 GHz and responsivity=0.5 A/W), we obtain 3.3dBm of modulated optical power without the insertion loss of a variable optical attenuator (VOA) that is used to adjust the optical signal power before the PIN photodetector. Afterward, the OOK signal is amplified by another amplifier (22 dB gain, 60 GHz bandwidth), however, for the PAM signal we use a different electrical amplifier (11 dB gain, 65 GHz bandwidth). Then the signal is sampled with 256 GSa/s UXR1104A Infiniium UXR-Serie digital storage oscilloscope (DSO) and processed offline using a typical DSP routine, consisting of a low-pass filter (LPF), a timing recovery, a decision feedback equalizer (DFE), and an error counter. The actual photo of the setup is given in Fig.1(d).

3. Results and discussions

We use several forward error correction (FEC) thresholds for the result analysis. But we compare all modulation formats at a 6.25% overhead (OH) hard-decision forward error (HD-FEC) threshold of 4.5×10^{-3}. We evaluate the performance for optical back-to-back (ob2b) and after transmission over 200 meters of single-mode fiber.

In Fig. 2(a), we show the bit error rate (BER) as a function of received optical power (RX_{power}) for 170 Gbaud and 200 Gbaud OOK signals using the DFE with 55 feed-forward taps (FFT) and 13 feedback taps (FBT). The number of taps in the DFE can be relaxed (see Fig. 3). We use this configuration to show that there is still a margin

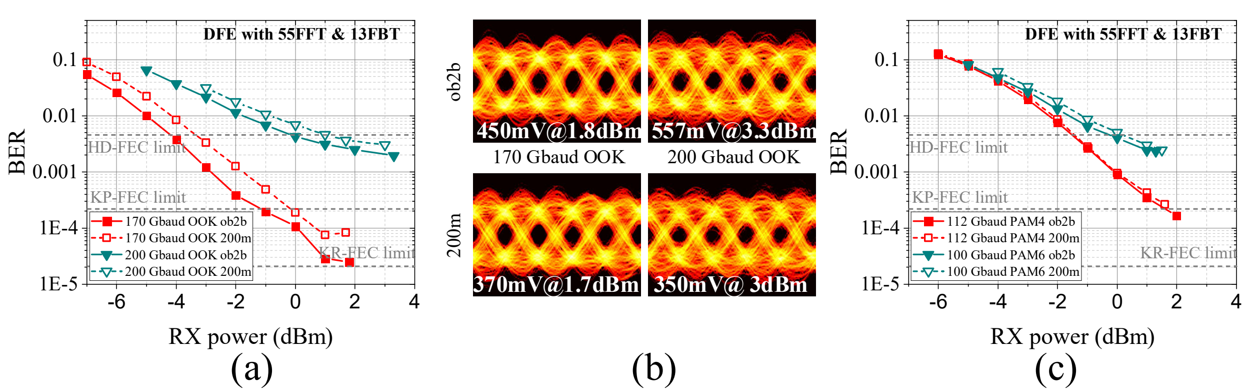

Fig. 2. (a) bit error rate (BER) versus received optical power (RX_{power}) for 170 Gbaud and 200 Gbaud OOK with a 55 FFT&13 FBT DFE, (b) eye diagrams (see insets), and (c) BER versus RX_{power} for 112 Gbaud PAM4 and 100 Gbaud PAM6 with a 55 FFT&13 FBT DFE.

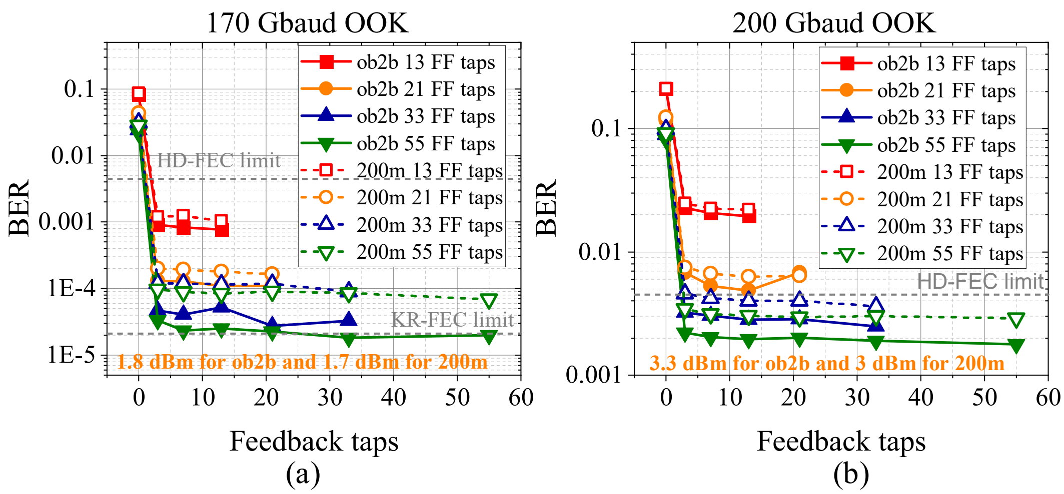

Fig. 3. Bit error rate versus tap numbers of decision feedback equalizer for (a) 170 Gbaud on-off keying, and (b) 200 Gbaud on-off keying links.

on the signal performance. We obtain the BERs below the HD-FEC requirements for both the ob2b and the 200 meters SMF; eye diagrams after the equalization with the opened eyes are shown beside. We also show values of the optical power received at the PIN photodetector and voltage at the 256 GSa/s UXR1104A Infiniium UXR-Serie DSO as insets. In Fig.2(c), we benchmark the transmitter (and optical link) performance using the 112 Gbaud PAM4 and 100 Gbaud PAM6 configurations.

A detailed analysis of the DFE impact on the 170 Gbaud and 200 Gbaud OOK signals quality is provided in Fig. 3. For the 170 Gbaud OOK setup, the signal quality allows achieving the KR-FEC threshold for the ob2b. Fiber dispersion sets a limitation on achievable performance. A feed-forward equalizer (FFE) was not enough to reduce the bit error rate below the HD-FEC limit; at least 3 FBTs were needed. Adding more FBTs did not improve the signal quality significantly. From Fig.3(c) one can see that the DFE configuration with just 33 FFT and 3 FBT brings the signal quality below the 6.25% OH HD-FEC threshold of 4.5×10^{-3} for the 200 Gbaud OOK optical link where no optical amplification is used thanks to the high output power of the C-band externally modulated laser.

4. Conclusions

In this paper, we transmit 200 Gbaud OOK signals over 200 meters of SMF without any optical amplification using the C-band EML. We achieve 3.3dBm of modulated output power at the optical transmitter output. The BER performance is well below the 6.25% OH HD-FEC threshold after the transmission over 200 meters of SMF.

5. Acknowledgement

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