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An All-optical Metro-Access Interface for a PON System Based on NRZ to FSK Format Conversion

Yuanyuan Lu, Cishuo Yan, Qingjiang Chang, Qiang Li, Yikai Su, Weisheng Hu
State Key Lab of Advanced Optical Communication Systems and Networks, Department of Electronic Engineering
Shanghai Jiao Tong University, 800 Dongchuan Rd, Shanghai 200240, China, yikaisu@sjtu.edu.cn

Abstract: We propose and experimentally demonstrate a novel all-optical NRZ to FSK format conversion scheme to interconnect a MAN and a PON system. Upstream data is re-modulated on downstream converted FSK format.

OCIS codes: (060.2330) Fiber optics communications; (060.2630) frequency modulation; (060.4250) Networks.

1. Introduction

Passive optical network (PON) has become an attractive solution to provide broadband access. To reduce the cost at the optical network units (ONUs), re-modulation on downstream data is a promising technique. The downstream signal possesses constant intensity serving as a carrier for re-modulation at the ONU. As frequency-shift-keying (FSK) format presents constant intensity, it has received considerable attention in PON applications [1-4]. In addition, FSK balanced detection enables 3-dB receiver-sensitivity enhancement, and higher tolerance to fibre nonlinear impairment and chromatic dispersion [5-7]. On the other hand, cost-effective non-return-to-zero (NRZ) format is widely used in metropolitan area networks (MANs). Therefore, NRZ to FSK format conversion would be desirable at an intermediate node. To the best of our knowledge, however, no demonstration has been performed on conversions from NRZ to FSK to interface a MAN and a PON system, which is expected to be a promising technology to provide scalable broadband access.

In this paper, we propose an all-optical metro-access interface based on NRZ to FSK conversion using a semiconductor optical amplifier (SOA) at an optical line terminal (OLT). At the ONU, part of the FSK signal is tapped off and detected by a balanced receiver, and the other part is fed into an optical intensity modulator for upstream re-modulation. Error-free operation is experimentally demonstrated to show the feasibility of the proposed scheme with a 10-Gb/s downstream data and a 1.25-Gb/s upstream data.

2. Principle of operation

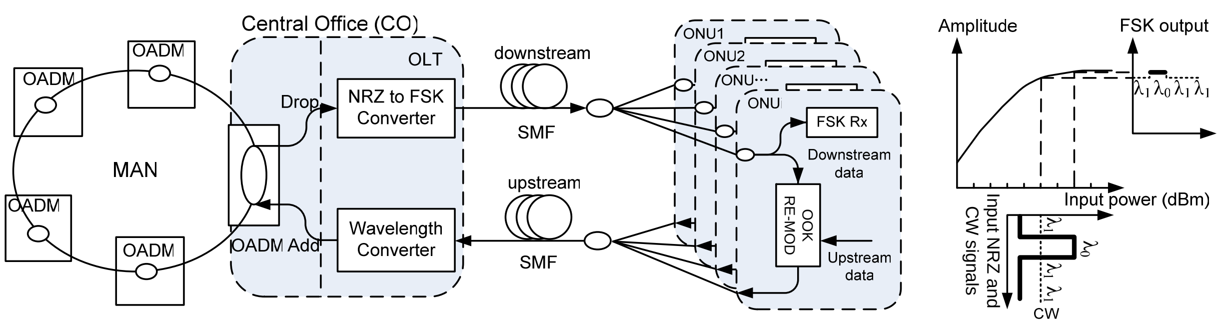

Fig. 1. (a) Network topology with an NRZ to FSK format converter between a metro network and a PON system. (b) Principle of the NRZ to FSK converter based on an SOA.

Figure 1(a) shows the network architecture with the proposed NRZ to FSK format converter at a central office (CO) between a MAN and a PON system. The CO comprises a reconfigurable optical add/drop multiplexer (OADM) as a metro node and an OLT for all ONUs. The format converter within the OLT acts as an all-optical interface to bridge the MAN and the access network. The basic principle of the NRZ to FSK converter as depicted in Fig. 1(b) is similar to a conventional wavelength converter, based on cross gain modulation (XGM) in a SOA operated in the saturation regime [8]. The incoming NRZ signal at wavelength λ_0 and a continuous-wave (CW) light at λ_1 are launched into the SOA as a control pulse and a probe light, respectively. As shown by the dotted line in Fig. 1(b), the power of the CW is set between the powers of "0" and "1" levels of the NRZ data. The carrier density in the SOA is varied depending on the intensity of the control pulse. Therefore, after passing through the SOA, the probe light carries inverted logical information as the NRZ. By adjusting the power of the NRZ and the probe, FSK signal with a constant intensity can be obtained at the output of the SOA, and the output wavelengths are changed depending on the input NRZ signal.

The converted FSK signal is transmitted over conventional single-mode fibre (SMF) as downstream data to an ONU, where the chromatic dispersion between the upper and the lower sidebands (USB and LSB) is compensated to preserve the constant intensity of the downstream FSK signal [5], before fed into an FSK receiver and an optical intensity remodulator. Part of the compensated FSK is tapped and received by a balanced receiver to obtain the 3-dB receiver-sensitivity enhancement [5]. The rest part is then intensity modulated with the upstream on-off-keying (OOK) data and is transmitted back to the OLT along another SMF to avoid Rayleigh backscattering.

3. Experiment

Figure 2 depicts the experimental setup to verify the operation principle of the format conversion and to demonstrate downstream and upstream transmissions between an OLT and an ONU. We use a commercial polarization-independent booster SOA (SOA-NL-OEC-1550 from CIP) with a gain recovery time of ~30 ps at 300 mA drive current. This SOA has a small signal gain of 30 dB and a saturation power of 10 dBm. The NRZ signal transmitted in a MAN is generated by modulating a CW light (LD1) at 1550.27 nm with a Mach-Zehnder modulator (MZM) using a 10-Gb/s pseudorandom bit sequence 1 (PRBS1) of length 2^7-1. An erbium-doped fiber amplifier (EDFA) amplifies the signal to 12 dBm, a tunable optical filter (TOF) with a bandwidth of 0.4 nm suppresses amplified spontaneous emission (ASE) noise, and a variable optical attenuator (VOA) reduces the power to 3 dBm. Another CW light at 1549.94 nm with a power of -2 dBm is coupled with the incoming NRZ signal and launched into the SOA simultaneously. At the output of the SOA, an FSK signal with almost constant intensity is obtained, whose eye diagram and spectrum are provided in insets (i) and (ii) of Fig. 2.

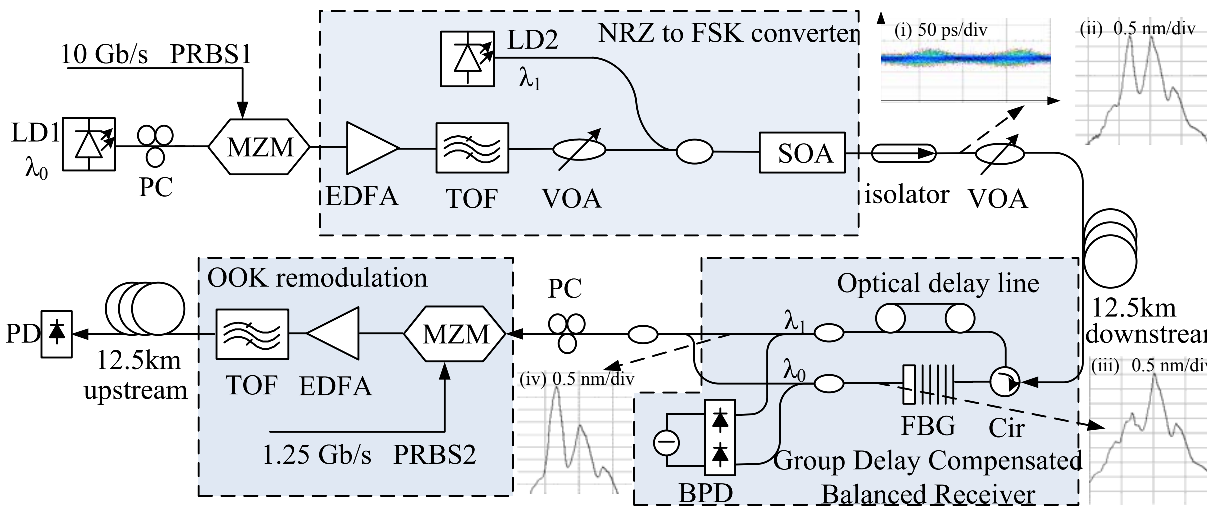

Fig. 2. Experimental setup. PC: Polarization controller; Cir: Circulator. Optical spectrum resolution: 0.07 nm.

The converted FSK signal is transmitted downstream through a VOA and a 12.5-km SMF to the ONU, where a fiber Bragg grating (FBG) with an optical circulator separates the USB (1550.27 nm) and LSB (1549.94 nm) tones. The FBG has a reflective bandwidth of 0.2 nm at 1549.94 nm. In the experiment we used an optical delay line to compensate the group delay difference between the USB and LSB, while in practice this can be achieved using electronic tunable delay compensation for different transmission distances. The spectra of the USB and LSB components are illustrated in insets (iii) and (iv) of Fig. 2. Both the suppression ratios are ~15 dB. The two sidebands are split into two parts by two 50/50 couplers. One part is received by a 10-GHz balanced photodetector (BPD). The other part recombines and is remodulated by a 1.25-Gb/s PRBS2 of length 2^7-1 in a MZM. The upstream NRZ signal is amplified and sent over a 12.5-km SMF back to the OLT, where it is detected by a 2.5-GHz photodetector (PD). The downstream and upstream electrical NRZ signals are generated by the front and back panels of a programmable pulse pattern generator (PPG, MP1763C from Anritsu), respectively. To facilitate the programming and bit error rate (BER) testing processes, we chose the pattern length of 2^7-1. In fact, the pattern length is not limited to 2^7-1 because the gain recovery time of the SOA is as short as ~30 ps.

Figure 3 shows BER curves and eye diagrams for the format converted, downstream, and upstream signals. For the NRZ to FSK format conversion, the power penalty of the FSK signal received by a BPD is ~1.2 dB. The reflection ratio of the FBG is ~90%, which results in that the power of the LSB is lower than that of the USB.

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Therefore, the BERs of the USB and LSB detected by a single-end PD are different, which can be avoided using an interleaver with higher suppression ratio [5]. The optical and electrical eye diagrams of the USB and LSB are illustrated in Fig. 3(b). The insets of Fig. 3(c) show that the demodulated eye diagrams of the converted FSK before and after the transmission have nearly the same shape. Yet the eye diagram after the transmission displays more noise, which results in ~0.4-dB penalty. The eye diagrams and BER performance in Fig. 3(d) indicate that the upstream transmission suffers ~1-dB penalty due to the dispersion between the two wavelengths of the remodulated NRZ.

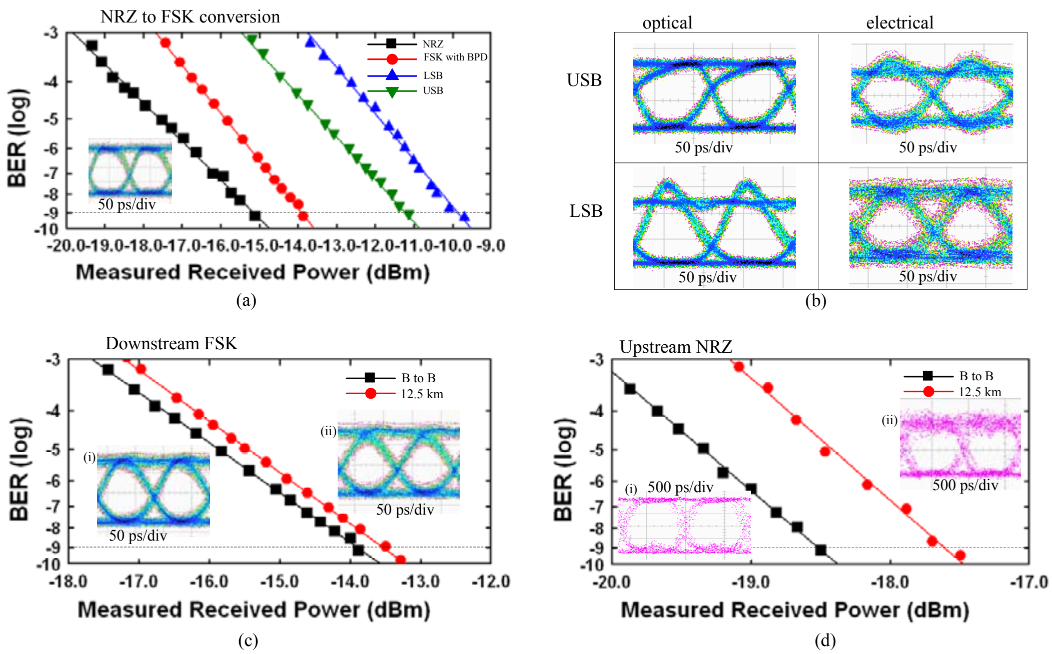

Fig. 3. (a) BER curves and eye diagrams in the format conversion process; (b) Eye diagrams of the USB and LSB signals; (c) FSK-signal transmission performance; (d) Upstream remodulated-signal performance.

4. Conclusion

We have proposed and experimentally demonstrated an all-optical NRZ to FSK format conversion scheme at an OLT to interconnect a MAN and a PON. The constant intensity of the converted downstream FSK signal is remodulated at the ONU to carry upstream data. Error-free conversion has been achieved at 10 Gb/s based on XGM in an SOA with a power penalty of 1.2 dB. 1.25-Gb/s upstream remodulation and transmission are also demonstrated.

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