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RESEARCH ARTICLE

160-Gbit/s clock recovery using an electro-absorption modulator and 40-Gbit/s ETDM demultiplexer

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Abstract A 10-GHz clock recovery from a 16×10-Gbit/s optical time-division-multiplexed (OTDM) data stream is experimentally demonstrated using an electro-absorption modulator and 40-Gbit/s electric time-division-multiplexed (ETDM) demultiplexer. The recovered clock signal exhibits excellent stability, with root square (RMS) jitter of 328 and 345 fs corresponding to back-to-back and transmission over 100 km, respectively.

Keywords optical time-division-multiplexed (OTDM), clock recovery, 160-Gbit/s

1 Introduction

In future high-speed optical time-division-multiplexed (OTDM) networks, clock recovery (CR) at tributary rates from the multiplexed data stream will be an essential process as it synchronizes operations such as demultiplexing and 3R data regeneration at each network node. Many CR technologies have been investigated, including phase-locked loop (PLL) [1,2], nonlinear optical loop mirror (NOLM) [3], cross-grain modulation (XGM) [4], two-photon absorption [5], and so on. Elector-absorption modulator (EAM) is a promising device in high-speed optical signal processing because of their low polarization dependence, easy handling, and high integrability. In this paper, we report an EAM and 40-Gbit/s electric time-division-multiplexed (ETDM) demultiplexer [6] for 10 GHz clock extraction from a 16×10-Gbit/s OTDM signal.

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2 Experimental setup

The solid box of Fig. 1 shows the setup of 160-Gbit/s transmitter. It comprises mode-locked fiber ring laser (MLFL) (CALMAR OPTCOM Model: PSL-10-1T), a modulator and a passive multiplexer. The MLFL generated a pulse train with a repetition rate of 10 GHz (9.95328 GHz) at a wavelength of 1556.223 nm. The emitted pulses are the shape of a $sech^2$-function and a full-width at half-maximum (FWHM) of less than 1.5 ps. The 10 GHz pulse train is intensity modulated with a pseudo random bit-sequence (PRBS 2^7-1) by an external $LiNbO_3$ modulator. Then, the 10-Gbit/s data signal is multiplexed to 160-Gbit/s by a home-made multiplexer.

Conventional OTDM multiplexer is based on fused fiber coupler, and its performance is usually degraded due to polarization fluctuation of the input signal, which will rapidly change the distribution of output power among adjacent multiplexed pulses [7,8]. Recently, reported OTDM multiplexers [9,10] can provide qualified and stable OTDM signals but is not widely used in practice due to their high cost. In this work, we propose a cost-effective and low polarization dependent structure to achieve the multiplexing. The home-made multiplexer consists of four-stage OTDM multiplexer based on plated graded index (GRIN) lens, which consists of two reverse-connected GRIN lenses coupled with three fiber pigtails and performs the same function as fused fiber coupler. A very thin half-reflection-half-transmittance (HRHT) mirror is plated between two lenses, as shown in Fig. 2. This structure is based on GRIN lens exhibits low polarization dependence [11].

Two plated GRIN lenses aforementioned compose one stage multiplexer, as illustrated in Fig. 3. Ports 3 and 3’ are coupled directly, and a fiber delay line is added between Ports 2 and 2’. Then, the signal at Port 1 is doubled and multiplexed at Port 1’. Our four-stage multiplexer consists

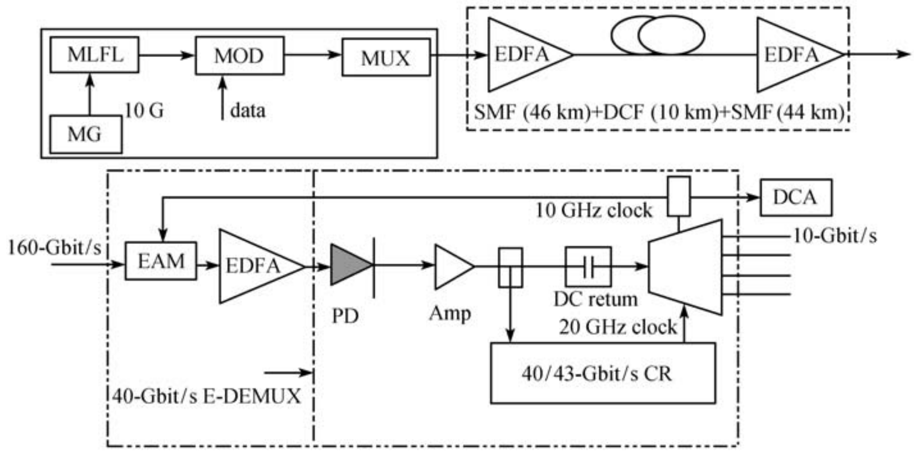

Fig. 1 Experimental setup (MLFL: mode-locked fiber ring laser; MOD: $LiNbO_3$ modulator; MUX: passive 10-to-160-Gbit/s multiplexer; MG: microwave generator; EDFA: erbium-doped fiber amplifer; SMF: single-mode fiber; DCF: dispersion compensating fiber; EAM: elector-absorption modulator; PD: photodiode; Amp: microwave amplifier; DEMUX: demultiplexer; CR: clock recovery; DCA: digital communication analysis)

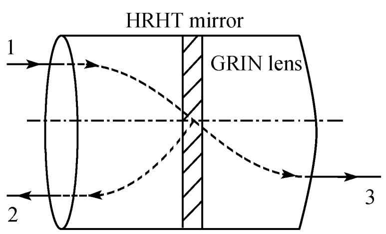

Fig. 2 Structure of plated GRIN lens and inner optical paths

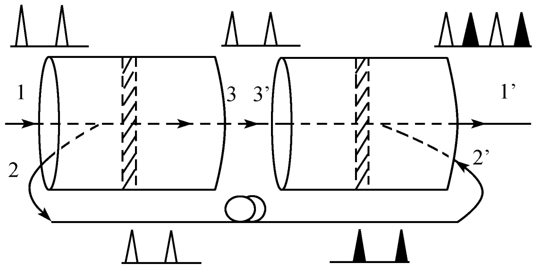

Fig. 3 Structure of SMUX based on plated GRIN lens

of four pairs of such cascaded lenses. The delay times in each stage are 50, 25, 12.5, and 6.25 ps, respectively. The insertion loss of each stage is about 4.5 dB, and thus, the total insertion loss of the four-stage multiplexer is about 18 dB.

The dashed box of Fig. 1 shows the setup of the transmission link. The total length of fiber is ~100 km, which is composed by ~90 km single-mode fiber (SMF) and ~10 km dispersion slope compensation fiber (DSCF) (both fabricated by Yangtze Optical Fiber and Cable Company: YOFC). The insertion loss of DSCF is 6.89 dB, and the total insertion loss of fiber span is ~29 dB including all splices and connectors. The DSCF is designed to achieve both zero chromatic dispersion and slop at 1550 nm wavelength band for 90 km SMF. At 1556.223 nm, the dispersion and slope values are -150.432 ps/(nm·km) and -4.931 ps/(nm^2·km), respectively, for DSCF, and 16.723 ps/(nm·km) and 0.058 ps/(nm^2·km), respectively, for SMF. The DSCF is placed in the middle of the transmission link, which has been shown to be better than predispersion and postdispersion compensation schemes [12].

After transmission over 100 km, the multiplexed 160-Gbit/s signal is put into the demultiplexer (DEMUX), which consists of an EAM and 40-Gbit/s ETDM demultiplexer (dash-dotted box). The EAM, a high-speed semiconductor device driven by 10 GHz RF signal, is able to generate <25 ps (FWHM) temporal optical sampling windows. The 40-Gbit/s ETDM demultiplexer comprises a 40 GHz photodiode (PD), microwave amplifier, 40/43-Gbit/s CR unit (made by SHF Company) that can recover 20 GHz clock from 40/43-Gbit/s signal and 4:1 demultiplexer (made by SHF Company). As shown in Fig. 1, the electrical 10 GHz clock signal extracted by 4:1 demultiplexer is divided into two parts. One part is used for observation on the digital communication analysis (DCA), and the other part is fed into the electrical input of the EAM. Therefore, the EAM and 40-Gbit/s ETDM demultiplexer form the clock recovery loop.

3 Results and discussion

Figures 4(a) and 4(b) show the eye diagrams of multiplexed 160-Gbit/s signal before and after transmission, respectively. Because the bandwidth of our oscilloscope (Agilent DCA 86100 B) is only 53 GHz, the eye diagrams of 160-Gbit/s are not real ones. Compared to Fig. 4(a), Fig. 4(b) has a little jitter. It is proven that the dispersion is compensated well.

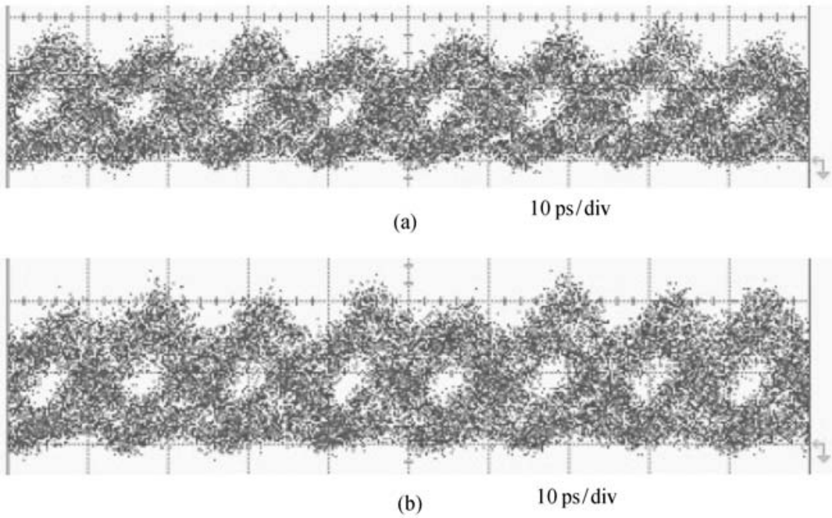

Fig. 4 Eye diagrams of 160-Gbit/s signal. (a) Before transmission; (b) after transmission

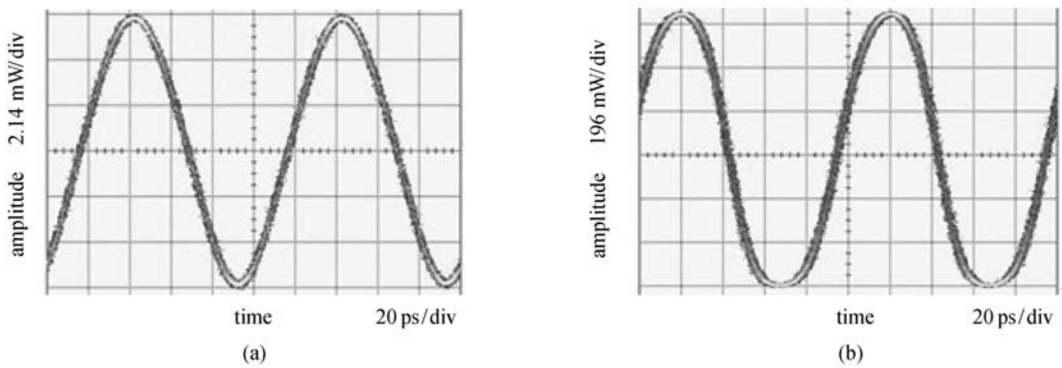

Fig. 5 Waveform of 10 GHz clock recovered from 160-to-10-Gbit/s. (a) Back-to-back; (b) transmission over 100 km

Figure 5 shows the waveform of 10 GHz clock extracted from 160-Gbit/s for back-to-back and transmission over 100 km. The root mean square (RMS) jitter of 10 GHz clock recovered from multiplexed 160-Gbit/s signal is 328 and 345 fs for back-to-back and transmission over 100 km, respectively. The difference of amplitude and jitter of Figs. 4(a) and 4(b) is small. This expresses that the transmission link has little impact on CR, and also, the performance of CR is stable. With respect to the results of other foreign experiment groups [1,2], the RMS jitter of our recovered clock is larger. This is maybe introduced by the following reasons: the jitter of pulse source, polarization mode dispersion (PMD) of transmission link, and the amplified spontaneous emission (ASE) noise of EDFA.

4 Conclusion

10 GHz clock recovery from 160-Gbit/s OTDM data signal is demonstrated using an EAM and 40-Gbit/s ETDM demultiplexer for back-to-back and transmission over 100 km. The RMS jitters of the recovered clock are 328 and 345 fs, respectively.

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