SIMULTANEOUS DEMULTIPLEXING, ELECTRICAL CLOCK RECOVERY, AND OPTICAL CLOCK GENERATION USING PHOTOCURRENT AND SUBHARMONIC FREQUENCY IN A TRAVELING-WAVE ELECTROABSORPTION MODULATOR

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Abstract *We demonstrate for the first time using a traveling-wave electroabsorption modulator simultaneously as a photodetector, a demultiplexer, and an optical pulse generator for clock-recovery and demultiplexing at line-rates of 40 Gb/s and 160 Gb/s.*

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Introduction

Compact optoelectronics components are desired to bring down the cost and ease the maintenance in high capacity optical communication systems. One way to realize this is through monolithic integration of different devices. Another possibility is to explore more functions in a single device. In this paper, we demonstrate three co-existing functions in a traveling-wave electroabsorption modulator (TW-EAM) [1]: detection, demultiplexing, and pulse generation. This is made possible by utilizing the photocurrent and subharmonic frequency in the device. With the addition of a phase-locked loop (PLL) [2], simultaneous demultiplexing, electrical clock recovery, and optical clock generation is realized at 40 Gb/s. This approach is further extended to a line-rate of 160 Gb/s by adding another EAM.

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Principle of Operation

Fig. 1(a) shows the setup of this approach for 40 Gb/s operation. The PLL requires an electrical 40 GHz tone extracted from the input 40 Gb/s RZ signal to recover a synchronized 10 GHz clock. This 40 GHz tone is provided by the photocurrent signal coming out of the upper electrical port of the TW-EAM. The 3-dB bandwidth of the TW-EAM as a photodetector [3] is 12 GHz but the roll-off is not fast. At 5 dBm of optical input the electrical 40 GHz tone from the TW-EAM is –36 dBm as shown in Fig. 2(a), which is 30 dB higher than the minimum power level required for phase-locking. The recovered 10 GHz clock is fed back into the lower electrical port of the TW-EAM with a proper phase to generate a gating window for demultiplexing 40 Gb/s to 10 Gb/s and for generating a synchronized 10 GHz optical clock at another wavelength simultaneously. The applied 10 GHz electrical clock travels through the TW-EAM and finally gets blocked by the 40GHz band-pass filter (BPF) at the input of the PLL. As a result, simultaneous demultiplexing, electrical clock recovery

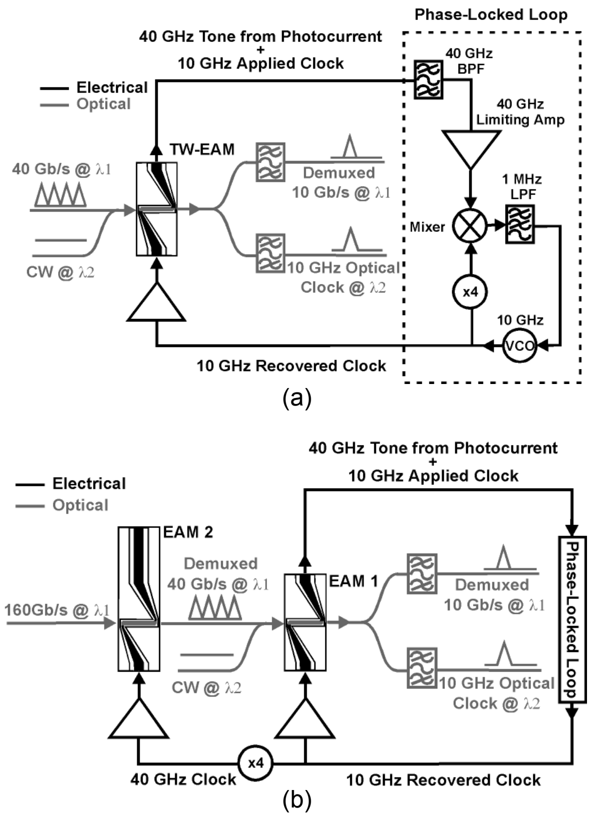

Fig. 1: (a) 40-Gb/s setup (b) Extension to 160 Gb/s

and optical clock generation is achieved by utilizing the photocurrent and subharmonic frequency in a TW-EAM. The generated optical clock is separated from the demultiplexed signal by an optical filter. If a counter-propagating scheme is used instead, the wavelength of the optical clock can be the same as the signal wavelength. This scheme can be extended to line-rates of N×40 Gb/s by adding another stage of demultiplexer in the front to extract a 40 Gb/s signal from the higher line-rate [4]. Fig. 1(b) shows the simplified setup for the 160 Gb/s experiment, where an EAM is used as the front demultiplexer.

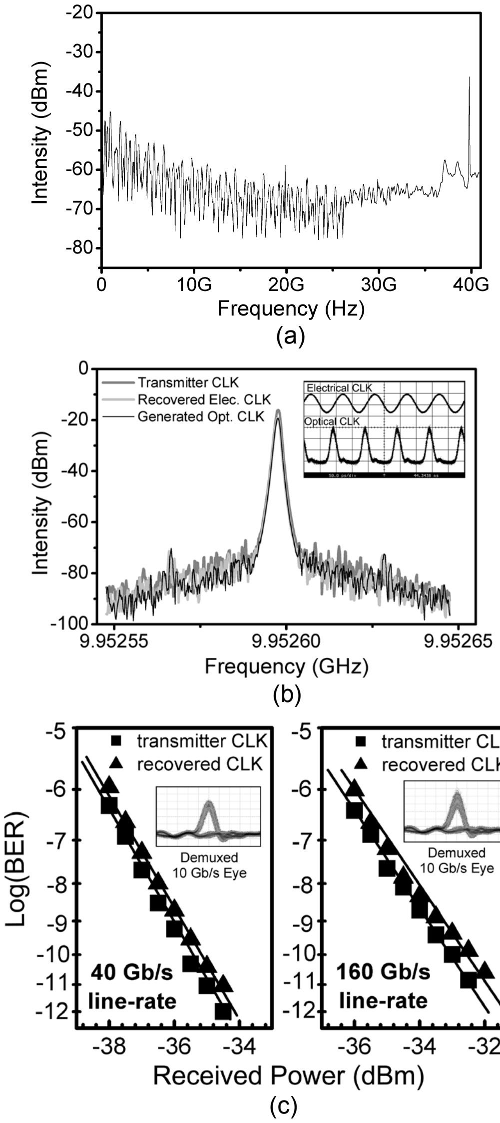

Fig. 2: (a) Photocurrent spectrum of TW-EAM at 5-dBm 40-Gb/s RZ input (b) RF spectrum of the transmitter clock, the recovered electrical clock, and the optical clock (c) Demuxed 10 Gb/s BER

40 Gb/s Experiment

The 40 Gb/s RZ signal at 1555 nm is multiplexed from 10 Gb/s RZ which is generated by modulating 10 GHz, 5 ps optical pulses from a mode-locked fiber ring laser using a $LiNbO_3$ modulator with 2^{31}-1 PRBS. The CW light for optical clock generation is 6 dBm at 1560 nm. A 2.4 nm optical band-pass filter is used to separate the demultiplexed 10 Gb/s signal at 1555 nm and the generated 10 GHz optical clock at 1560 nm. The 10 GHz electrical clock signal is amplified to 6 V_{p-p} to drive the TW-EAM for demultiplexing and optical clock generation. At 5 dBm of 40 Gb/s optical input, the locking range of the PLL using TW-EAM as a photodetector is 0.764 MHz. The absolute RMS timing jitter of the clock can be obtained from the RF spectrum in Fig. 2(b) by integrating the single side-band (SSB) noise [5]. The RMS timing jitter for the transmitter clock, the recovered electrical clock, and the generated optical clock (with EDFA amplification) are 223 fs, 231 fs, and 232 fs, respectively. The pulsewidth of the generated optical clock is 14 ps. Fig. 2(c) shows the bit-error-rate (BER) curves. BER comparison is done by switching the 10 GHz electrical clock supplied to the TW-EAM and the BER tester from the transmitter clock (back-to-back) to the recovered electrical clock. The power penalty is less than 0.2 dB for using the recovered clock, which is low and close to the measurement resolution.

160 Gb/s Experiment

The setup for 160 Gb/s is shown in Fig. 1(b). EAM 2, which has a standing-wave enhanced design [6], is adopted as the front demultiplexer and is driven by a 6 V_{p-p}, 40 GHz signal multiplied from the 10 GHz recovered clock to generate a gating window of 5 ps at the TE polarization. An EDFA and a 2.4 nm optical filter is inserted between the two EAMs to compensate for the loss, which is not shown specifically. To operate at 160 Gb/s, the 10 GHz pulses are compressed nonlinearly to 2 ps before modulation. However, the compressed pulses have relatively long tails so the 160 Gb/s RZ signal (5 dBm) is multiplexed with alternating polarization to minimize intersymbol interference since the loss of the EAM is higher for the TM polarization, which reduces the interference from adjacent channels. The measured RMS timing jitters are 216 fs, 224 fs, and 229 fs for the transmitter clock, the recovered electrical clock and the generated optical clock. The power penalty for using the recovered clock is less than 0.5 dB.

Conclusions

Simultaneous demultiplexing, electrical clock recovery and optical clock generation using a single TW-EAM is demonstrated for the first time by utilizing photocurrent detection and different frequency / wavelength components in the device. The recovered electrical clock and the generated optical clock have timing jitters comparable to that of the transmitter clock. This concept is demonstrated at 40 Gb/s and extended to 160 Gb/s by simply adding another EAM and can be scaled to even higher bit-rates with a proper front demultiplexer. Very low power penalties are obtained at both line-rates.

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