Novel photocurrent-assisted wavelength (PAW) converter using a traveling-wave electroabsorption modulator with signal monitoring and regeneration capabilities

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Abstract: We report on a novel photocurrent-assisted wavelength converter using a traveling-wave electroabsorption modulator which also provides electrical monitoring and regeneration capabilities. The proposed concept is demonstrated with 2.5-Gb/s NRZ and 10-Gb/s RZ data formats.

OCIS codes: (060.2330) Fiber optics communications, (060.2340) Fiber optics components

1. Introduction

Wavelength converters are key elements to enable flexible bandwidth allocation in optical networks. The realization of wavelength converters using semiconductor-based devices is of particular interest for its compactness and integration potential. Electroabsoprtion modulators (EAMs) have been demonstrated as wavelength converters by utilizing either cross-absorption modulation (XAM) [1] or cross-phase modulation (XPM) [2]. Compared to XPM, XAM has a simpler configuration and can be more attractive at lower bit-rates. However, the high pumping power is still an issue and also affects the long term reliability. XAM in EAMs is generally attributed to the field screening effect caused by a large number of charged carriers generated by the pump. The screening of the external field changes the absorption of the EAM and thus imprints data to the probe. In other words, the underlying mechanism is absorption saturation and high pumping power is required for a high extinction ratio.

In this work, we propose and demonstrate that in a traveling-wave EAM (TW-EAM) [3], there exists another XAM mechanism which does not require absorption saturation and can potentially lower the pumping power. This new mechanism utilizes the photocurrent signal generated by the pump to change the absorption and provide additional monitoring capability. To further improve the performance for RZ data, an RF-driven approach [4] is adopted to provide re-shaping and re-timing. We demonstrated these features with 2.5 Gb/s NRZ and 10 Gb/s RZ data formats.

2. Photocurrent-assisted Wavelength Converter (PAW-Converter)

The configuration of PAW-Converter is shown in Fig. 1. The TW-EAM is designed with traveling-wave electrodes (CPW line) and has a 300μm active waveguide. The pump is absorbed within a short distance near the input facet and generates photocurrent signal propagating in both directions of the CPW line. The co-propagating part of the photocurrent signal travels through the rest of the active waveguide and changes the local voltage and hence the absorption experienced by the probe. The photocurrent signal finally reaches port 1 and can be detected by an outside circuit to provide electrical monitoring. On the other hand, the counter-propagating part of the photocurrent signal goes to the termination at port 2. If the termination is 50 Ohm, the photocurrent signal is terminated. However, it will be reflected and becomes co-propagating if the termination is an open. The probe is selected after the conversion with a 2.4 nm optical band-pass filter. Fig. 2 shows the eye diagrams of the electrical signal from port

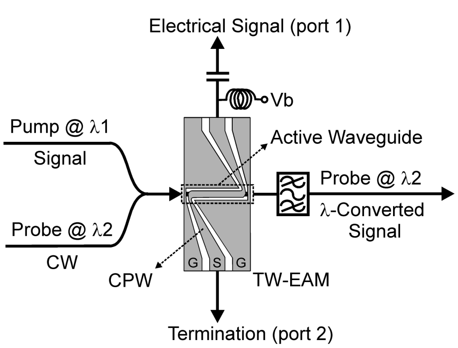

Fig. 1. Configuration of PAW-Converter

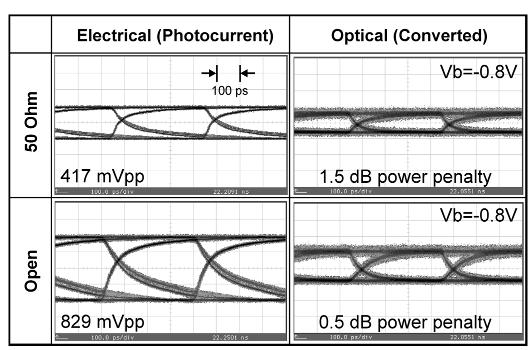

Fig. 2. 2.5-Gb/s NRZ eye diagrams

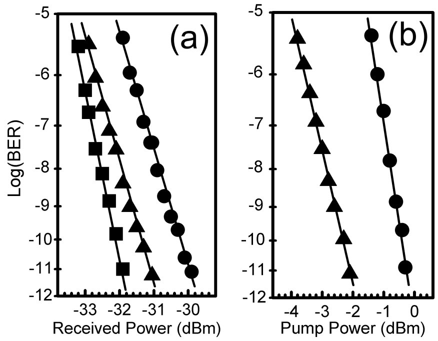

Fig. 3. BER curves (a) optical; (b) electrical. Square: Back -to-back; Triangle: Open; Circle: 50 Ohm

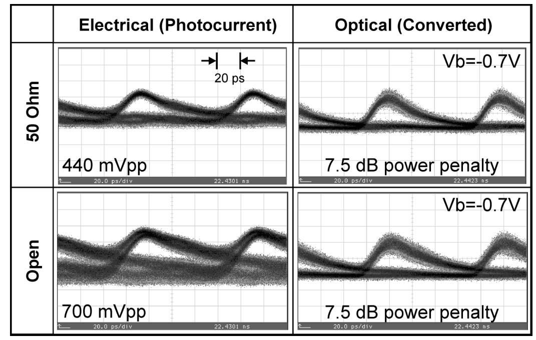

Fig. 4. 10-Gb/s RZ eye diagrams (no RF-drive)

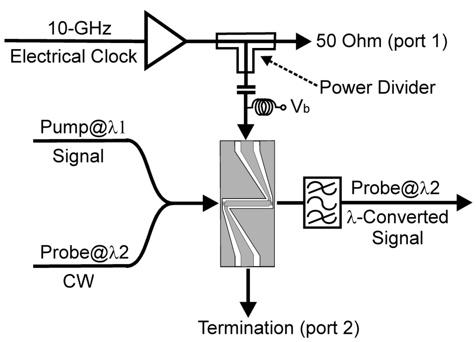

Fig. 5. RF-driven PAW-Converter

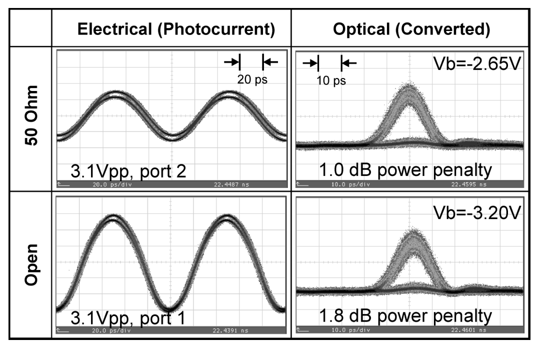

Fig. 6. 10-Gb/s RZ eye diagrams (with RF-drive)

1 and the converted optical signal. The pump is 13 dBm at 1545.8 nm and the probe is 1 dBm CW at 1555.2 nm. The electrical eye amplitude with open termination is doubled compared to that with 50 Ohm termination, due to the reflection at port 2. As a result, its corresponding optical eye is larger and has a higher extinction ratio (10.9dB v.s. 7.5dB) which results in a lower power penalty (0.5 dB v.s. 1.5 dB) as shown in Fig. 3(a). It can be inferred that the saturation mechanism contributes 4.1dB (10.9-(10.9-7.5)*2) of extinction ratio and the photocurrent-assisted mechanism contributes 6.8dB (10.9-4.1) for the open termination and 3.4dB (7.5-4.1) for the 50 Ohm termination. It is evident that the photocurrent-assisted mechanism can contribute more than the saturation mechanism in a TW-EAM. The electrical signal from port 1 can be fed into the BERT directly and no error was detected. The pump power is lowered to measure the BER curves and the open has a better receiver sensitivity because of its larger eye amplitude. Note that the pumping power required for NRZ conversion using PAW-Converter is comparable to that required for RZ conversion with 10% pulsewidth using lumped-EAM utilizing only saturation mechanism [5]. This would suggest a 10 dB higher pumping power if the NRZ conversion were carried out with a lumped-EAM.

The current TW-EAM is designed to operate with low bias voltage, which gives a longer carrier sweep-out time. This results in a long fall time of the electrical eyes in Fig. 2 and Fig. 3 for 2.5 Gb/s NRZ and 10 Gb/s RZ (12 ps pulsewidth, 13 dBm pump) conversions, respectively. The nonlinear E-O transfer function of the TW-EAM helps to minimize the effect of long fall time on the 2.5 Gb/s NRZ but the converted 10 Gb/s RZ is still distorted, which gives 7.5 dB of power penalty. The fall time is worse for the open termination due to multiple reflections. So, even though its eye amplitude is larger the power penalty is the same as that with 50 Ohm termination.

3. PAW-Converter with RF-drive

To reduce the effect of long fall time on RZ data, an RF-driven approach is adopted, as shown in Fig. 5 where a synchronized 10 GHz sinusoidal RF is fed into the TW-EAM through a power divider which reduces back-reflection from the amplifier and also provides electrical monitoring for the open termination. This approach was originally proposed to re-shape the converted RZ signal in conventional EAM-based wavelength converter because the applied RF-drive can increase the bias voltage momentarily to reduce the carrier sweep-out time provided the phase is adjusted properly [4]. Consequently, the tails of the converted RZ signal can be trimmed. When applied with PAW-Converter, the RF-drive not only increases the bias voltage momentarily but also mixes with the photocurrent signal.

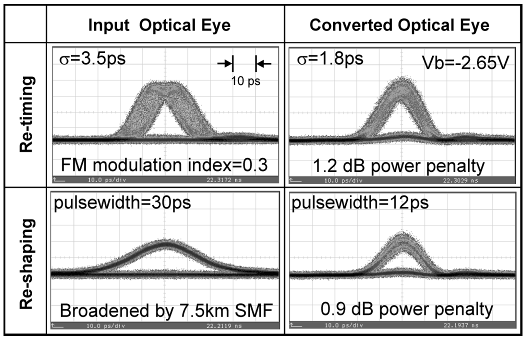

Fig. 7. Eye diagrams for regenerations

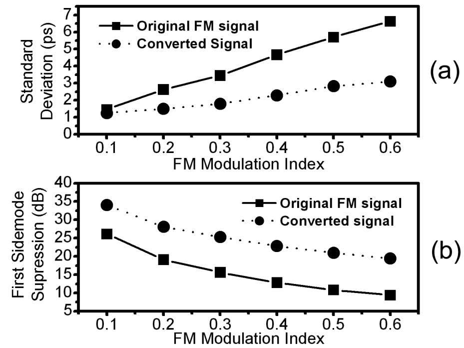

Fig. 8. Re-timing results (a) standard deviation; (b) first side-mode suppression ratio

Therefore, the trimming effect is further enhanced through the nonlinear E-O transfer function and the shape of the converted signal is mainly determined by the RF-drive because of its stronger magnitude. Fig. 6 shows the eye diagrams. The electrical eye is a combination of photocurrent signal and the applied RF-drive. BER measurement of these electrical signals is possible given a matched low-pass filter to remove the strong 10 GHz tone. The converted optical RZ eyes are well shaped and have less noise. The bias voltages are adjusted to minimize the power penalty. The power penalty is 1.0 dB with 50 Ohm termination and 1.8 dB with open termination. The higher penalty for the open termination is caused by the multiple reflections between the open and the amplifier. The 1.0 dB penalty for the 50 Ohm can be attributed to the finite extinction ratio, residue ISI, and also some reflections from the amplifier.

4. Re-timing and Re-shaping Capabilities

RF-driven PAW-Converter can have re-timing and re-shaping capabilities. To evaluate re-timing of the converted signal, the pulse train in the transmitter is FM modulated but the 10 GHz RF-drive to the TW-EAM remains pure [4], which can also be a recovered clock. Fig. 7 shows the eyes of the FM modulated pump signal and the converted signal. The FM modulation index is 0.3 which corresponds to +/- 4.8 ps_{p-p} of jitter. The standard deviation measured with the sampling scope is 3.5 ps but after the conversion it is reduced to 1.8 ps. However, there is still a 1.2 dB of power penalty caused by other effects as stated above. As shown in Fig. 8(a), RF-driven PAW-Converter can consistently reduce the timing jitter by half up to a FM modulation index of 0.6. The first side-band suppression ratio of the FM modulation can also be reduced by 10 dB after conversion. Re-shaping capability is also demonstrated in Fig. 7, where the pump pulse is intentionally broadened to 30 ps but the average power is still 13 dBm. The converted signal has a reduced pulsewidth of 12 ps, which is determined by the RF-drive.

5. Conclusion

A photocurrent-assisted mechanism for wavelength conversion using a low-voltage TW-EAM is proposed and demonstrated for the first time. The proposed PAW-Converter inherently requires less pumping power since saturation of absorption is not necessary. It also provides additional electrical monitoring capability at the same time, which increases the overall power efficiency. The successful demonstration of NRZ conversion at 2.5 Gb/s shows advantages in pumping power over saturation-based EAM wavelength converters. The combination with an RF-drive further improves the performance of PAW-Converter for RZ data at 10 Gb/s. The applied RF-drive not only improves the carrier sweep-out time but also provides re-shaping and re-timing capabilities without using an extra optical pulse source. Therefore, RF-driven PAW-Converter will be a compact and efficient wavelength converter in future photonic networks.

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6. References

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