100-Gbit/s Amplitude and Phase Modulation Characterization of a Single-Drive, Low-Vπ Polymer Mach-Zehnder Modulator

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Abstract: A polymer single-drive Mach-Zehnder modulator is experimentally characterized using 100-Gbit/s serial data modulation. BER of 10⁻⁹ is achieved for both 100-Gbit/s NRZ-OOK and NRZ-DPSK signals without optical or electrical equalization. The modulator shows a 7-dB bandwidth at 110-GHz and the chirp as low as -0.0219 GHz.

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1. Introduction

It is clear that the communications community has much interest in 100-Gbit/s data channels as well as the significant potential for 400 Gbit/s and 1 Tbit/s in the near future [1, 2]. Although dual-polarization quadrature-phase-shift-keying (DP-QPSK), 4x25 Gbaud/s, is emerging as a common method to achieve 100-Gbit/s channels, there is still an increasing interest in ever-higher baud rates. One key threshold has been the desire to achieve 100-Gbaud/s data modulation from an optical modulator in order to open up the possibility of: serial electronic 100-Gbit/s data channels at 110-GHz and the chirp as low as -0.0219 GHz. Beyond the need for higher bit-rates, 100-Gbit/s modulators may play an important role in systems that cannot readily handle the dual-polarizations or multilevel encoding modulation, and for many short-reach applications in which serial 100-Gbit/s transmission may prove to be a cost-effective solution [6]. Advances in high-speed RF electronics and photo-detectors have enabled full electronic time-division-multiplexed (ETDM) systems in the 100-107 Gbit/s range [6-8]. One of the limiting components has typically been the limited bandwidth of the optical modulator [1, 9], resulting in the need for additional optical or electronic equalization techniques to correct for output data distortion [8, 9].

Recent modulator development with >100 GHz of modulation bandwidth has produced: (a) traveling-wave electro-absorption modulators (TWEAM) [10] showing 50-Gbit/s on-off-keyed (OOK) data, and (b) electro-optic (EO) polymer modulators [11, 12] showing 80-Gbit/s OOK and differential-phase-keying (DPSK). Note that phase modulation is difficult to produce using EAM devices but is achievable in the recent commercial EO polymer Mach-Zehnder modulator (MZM) in support of higher-order modulation formats [13]. To our knowledge, there has been no reported result for true 100-Gbit/s data for either OOK or PSK data modulation in which no external equalization techniques were used.

In this paper, we experimentally demonstrate the first broadband characterization of an EO polymer single-drive MZM. Broadband operation with error-free measurements up to 100 Gbit/s for the ETDM generated non-return-to-zero (NRZ) OOK and, for the first time, NRZ-DPSK is obtained without the assist of equalization. Eye diagrams of 100-Gbit/s NRZ-OOK and NRZ-DPSK as well as the S21 measurements of up to 110-GHz are measured to prove the >100-GHz modulation response of this MZM. Chirp factor of as low as -0.0219 GHz is also achieved at 100-Gbit/s for OOK modulation.

2. Modulator Parameters

This newly developed EO polymer MZM (GigOptix LX8901) is a single-end-drive version with a Vπ of 3.5V, which is around one half of that of the dual-drive we demonstrated previously [12] due to the use of push-pull operation. A network analyzer, which is capable of measurements up to 110 GHz, is used to characterize the frequency response of this MZM. The measured S21 parameter is shown in Fig. 1. The 3-dB and 7-dB bandwidth are around 65 GHz and 110 GHz, respectively, showing the capability of > 100-Gbaud/s data modulation. It is noted that the ripples occurred in the high-frequency range are partially caused by the cable bending during the S21 measurements. The S21 parameter of the earlier version (LX8900) is also shown in Fig. 1 for comparisons. Moreover, the insertion loss as a function of optical wavelength of the input signal is measured, as shown in Fig. 2. The minimum insertion loss is ~7.5 dB at 1570 nm. It is noted that the insertion loss is large as the wavelength is out...
of C-band, which is attributed to the optical coupling during packaging [11]. This modulator is biased through a current source, and thus we further measure the transmission power as a function of the bias current, as shown in Fig. 3. The maximum point and the minimum point are biased at approximately 54-mA and 83-mA, respectively.

Fig. 1. Measured S21 frequency responses. LX8901 is the single-drive model. LX8900 is the dual-drive model reported in [12].

Fig. 2. Insertion loss of this MZM as a function of the input signal’s optical wavelength.

Fig. 3. Transmission power as a function of the applied bias current on this MZM.

3. Experiment Setup and Broadband Data Modulation


Fig. 4 shows the experimental setup for 100-Gbit/s serial data modulation. The pulse pattern generator (SHF1011A) is driven by a 50-GHz RF clock source to provide two 50-Gbit/s data channels (i.e., data and the inverted data). Both channels are fed into an electrical multiplexer (SHF408) to generate a 100-Gbit/s data channel through ETDM. A state-of-the-art broadband amplifier (SHF804TL) with a 3-dB bandwidth of 55 GHz and usable gain bandwidth of > 80 GHz can amplify the data to an output voltage of ~3.2 V at 100-Gbit/s, close to the $V_{π}$ of the MZM. The amplified data is directly used to drive the MZM, which is biased using a current source, i.e., with ~18.4 mA for OOK and ~80.7 mA for DPSK. The wavelength of the input continuous-wave (CW) laser is 1550.14 nm, with an optical power of 16-dBm. The modulated optical signal is then sent into a 65 GHz optical sampling scope and a complex spectrum analyzer (CSA) (AP2440A) for measurements. The eye diagrams of the 100-Gbit/s ETDM data (after MUX) and optically modulated OOK data (after MZM) are shown in Fig. 4(a) and (b). It can be seen that the 100-Gbit/s optical eye is clean and open except for the existing of some inter-symbol interference (ISI) effects. This is partially due to the bandwidth limitation of the photo-detector equipped with the sampling scope, in which the maximum bandwidth is 65 GHz. We note that the actual quality of the measured 100-Gbit/s signal is expected to be much better than that shown in Fig. 4(b) if the bandwidth limitation can be released. Fig. 5 shows the optical waveform and chirp of the OOK signal measured by the CSA at 100-Gbit/s. We use a short pattern with 32-bits in length for the CSA. The measured average chirp can be as low as -0.0219 GHz with the bias current of 18.4 mA. The constellations of both generated 100-Gbit/s NRZ-OOK and NRZ-DPSK signals are also measured by the CSA and shown in Fig. 6.

The generated 100-Gbit/s NRZ-OOK signal is down-sampled to 12.5 Gbit/s by using an optical sampler (i.e., a nonlinear optical loop mirror) driven by a 12.5-GHz RF clock. The eye diagrams of the down-sampled NRZ-OOK
tributaries are shown in Fig. 7(a), respectively. It is noted that the relatively thick “1” level of the eye is due to the existing ISI effect. Each tributary is O/E converted by a photo-detector with a bandwidth of 50 GHz and then processed for BER measurement. Error-free performance (i.e., BER of 1E-9) is achieved for all 8 tributaries.

Moreover, the generated 100-Gbit/s NRZ-DPSK signal is also down-sampled and then sent to a 12.5-Gbit/s polarization-based DPSK demodulator (i.e., consisting of two polarization controllers, a differential-group-delay (DGD) element and a polarizer). The value of the DGD is fixed to 80 ps (i.e., free spectral range of 12.5 GHz) for proper demodulation. The eye-diagram for each tributary is shown in Fig. 7(b). We note that the demodulated eye-diagrams shown here are the “half eyes” of the balanced eye-diagrams since a polarizer is employed in the setup and only one end of a balanced detector is used. The measured BER curves are plotted with 2-dB better performance for OOK over DPSK. If balanced detection is utilized, a 3-dB improvement is expected for DPSK. The lower DPSK performance is attributed to the single ~Vπ peak-to-peak drive signal instead of the ideal 2Vπ.

Fig. 5. Measured optical waveform and chirp of 100-Gbit/s NRZ-OOK with bias current of 18.4-mA. The average chirp is as low as -0.0219 GHz.

Fig. 6. Measured constellations for the generated 100-Gbit/s optical signals. (a): NRZ-OOK with bias current of 18.4 mA. (b): NRZ-DPSK with bias current of 80.7 mA.

Fig. 7. Down-sampled & demodulated eye-diagrams and BER performance at 12.5 Gbit/s. (a): NRZ-OOK. (b): NRZ-DPSK.

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4. References
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