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Simple, low fluctuation voltage signal generation for 8-Gb/s quadrature amplitude modulation using dual-parallel Mach-Zehnder modulator

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Abstract: Optical quadrature amplitude modulation (QAM) has attracted considerable attention because of its high spectral efficiency. For high capacity, the modulation rate should also be enhanced, which requires the generation of high-baud-rate multilevel electric signals with high precision in amplitude. In this paper, we describe a method to reduce the amplitude fluctuation of the electric signal by adopting a return-to-zero (RZ) format. We also demonstrate 2.0-Gbaud optical QAM signal generation with a conventional dual-parallel Mach-Zehnder modulator (DPMZM) driven by the electric RZ data signals.

Keywords: Advanced modulation format, optical quadrature amplitude modulation, lithium niobate optical modulator, optical I-Q modulation, patterning effect suppression.

Classification: Photonics devices, circuits, and systems

References

[1] T. Kawanishi, T. Sakamoto, and M. Izutsu, "High-speed control of lightwave amplitude, phase, and frequency by use of electrooptic effect," *IEEE J. Sel. Topics Quantum Electron.*, vol. 13, no. 1, pp. 79–91, Jan.–Feb. 2007.

[2] M. Nakazawa, M. Yoshida, K. Kasai, and J. Hongou, "20 Msymbol/s, 64 and 128 QAM coherent optical transmission over 525 km using heterodyne detection with frequency-stabilized laser," *Electron. Lett.*, vol. 42, pp. 57–58, June 2006.

[3] N. Kikuchi, K. Mandai, K. Sekine, and S. Sasaki, "First experimental demonstration of single-polarization 50-Gbit/s 32-level (QASK and 8-DPSK) incoherent optical multilevel transmission," *Proc. OFC2007*, Anaheim, USA, no. PDP21, March 2007.

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[4] J. Hongou, K. Kasai, M. Yoshida, and M. Nakazawa, "1 Gsymbol/s, 64 QAM cohelent optical transmission over 150 km with a spectral efficiency of 3 Bit/s/Hz," *Proc. OFC2007*, Anaheim, USA, no. OMP3, March 2007.
[5] A. Chiba, T. Sakamoto, T. Kawanishi, and M. Izutsu, "Demonstration of optical quadrature amplitude modulation by using a high-speed optical DQPSK modulator and precise voltage-control technique," *Proc. OECC 2007*, Yokohama, Japan, no. 12B3-4, July 2007.
[6] T. Sakamoto, A. Chiba, and T. Kawanishi, "50 Gb/s 16 QAM by a quad-parallel Mach-Zehnder modulator," *Proc. ECOC2007*, Berlin, Germany, no. PD2.8, pp. 87–88., Sept. 2007.
[7] D.-S. Ly-Gagnon, K. Katoh, and K. Kikuchi, "Unrepeatered optical transmis- sion of 20 Gbit/s quadrature phase-shift keying signals over 210 km using homodyne phase-diversity receiver and digital signal processing," *Electron. Lett.*, vol. 41, no. 4, pp. 206–207, 2005.
[8] A. Chiba, T. Sakamoto, and T. Kawanishi, "Adaptive symbol discrimination method for distorted multi-level optical signal and its application to decoding of high-speed optical quadrature amplitude modulation," *Proc. OFC2008*, San Diego, USA, no. JWA63, Feb. 2008.
[9] Y. Mori, K. Igarashi, K. Katoh, and K. Kikuchi, "Carrier-phase estimation using adaptive equalization in digital coherent optical receivers," *Proc. 2008 IEICE General Conference*, Kitakyushu, Japan, no. B-10-99, March 2008.

1 Introduction

Currently lightwave signals can be precisely controlled by advanced lithium niobate (LN) optical vector modulator [1]. This has brought significant scientific interest into some of challenges of the complicated optical modulation techniques [2, 3] that promise enhanced data transportation rates. One such technique is quadrature amplitude modulation (QAM), which is conventionally used in wireless networks due to its high spectral efficiency. Since this feature also allow effective use of the limited frequency resources in optical communication, several experiments have already been attempted with conventional dual-parallel Mach-Zehnder modulators (DPMZMs) [4, 5]. Thus, the feasibility of optical QAM is attracting wide-spread attentions.

For an enhanced data transportation capacity, naturally, the modulation rate should also be increased, besides increasing the number of bits per symbol. However, previous demonstrations have been limited to modulation rates of up to 1 Gbaud due to the requirements for amplitude precision in the electrical data signals. The treatment of data signals becomes very sensitive at high modulation rates, which makes it very difficult to generate highly precise, high-speed multilevel electrical signals. To avoid this difficulty, a quad-parallel Mach-Zehnder modulator (QPMZM), where an optical QAM signal can be generated by superposing two optical quadruple phase-shift keying (QPSK) signals, has been proposed with which 12.5-Gbaud optical QAM signal has been generated [6]. The main feature of this signal generation technique is that binary electric signals, which can be generated without any patterning effects, are converted into optical signals and the optical sig-

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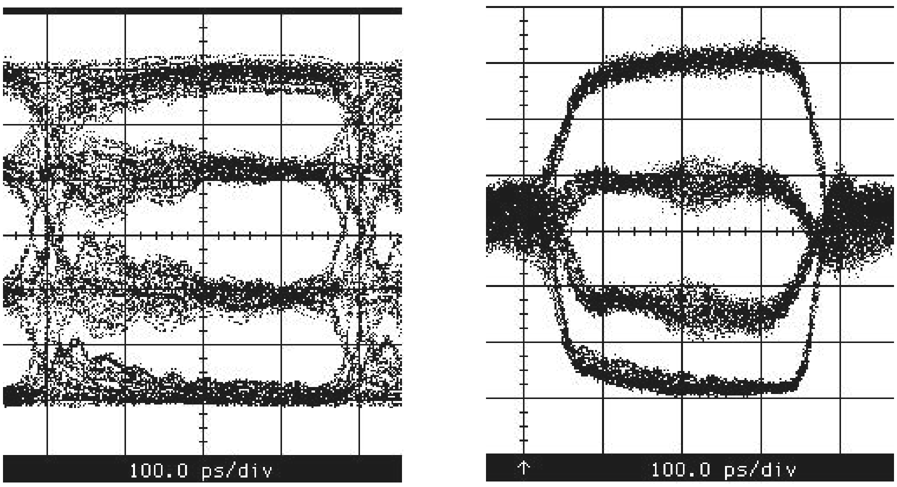
nals are superposed with adequate phase relations. However, this requires that the relative phases between each optical binary signal are adjusted and stabilized, making management of the relative phase very complicated.

In this paper, we report the generation of a 2.0-Gbaud optical QAM signal with a conventional DPMZM driven by four-level signals precisely equalized in a simple manner. Distortion of electrical multilevel signal mainly originates from the transient response of the rf amplifiers that drive the optical modulator. Such distortion can be suppressed by introducing zero-voltage intervals between each multilevel data signal, i.e., return-to-zero (RZ) multilevel electrical signals. The interval eliminates the electrical hysteresis accumulated in the rf amplifiers without complicated signal processing technique. This data signal generation method is very simple and can be easily applied to the construction of an optical modulation system that requires precise voltage control.

2 Generation of optical QAM signal

2.1 Preparation and quality evaluation of electrical signal for modulation

Electric signals for multilevel optical modulation should have very little amplitude fluctuation. However, rf amplifiers, which are usually indispensable for driving LN optical modulators, introduce excess noise into their output signals due to their amplitude-dependent responses, i.e., the patterning effect, in addition to the transient response and white noise of their components. In particular, suppression of the patterning effect is necessary for any optical multilevel modulation system when the modulation rate is increased. Since the patterning effect originates from the hysteresis of the rf amplifier, we attempted to erase the hysteresis by introducing interval times in the electric



(a) (b)

Fig. 1. Eye pattern of four-level (a) NRZ signal and (b) RZ signal for optical modulation. Ranges of horizontal and vertical axes are 100 ps/div. and 1 V/div., respectively.

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signal.

Figure 1 shows the eye patterns of a multilevel electric signal for modulation. Figure 1 (a) and 1 (b) are the cases for a 2.5-Gbaud no-return-to-zero (NRZ) signal and a 2.0-Gbaud RZ signal, respectively. In Fig. 1 (a), time-dependent level fluctuations are observed due to overshooting, especially in the timing of rises/drops. The results show that it takes more than 300 ps for the effect of overshooting to decrease. In contrast, in Fig. 1 (b), each signal level contains no pattering effect, making the levels almost flat and leading to a clear eye opening between all the signal levels. Thus, tolerance to the sampling timing at the receiver would be improved by adopting the RZ signal. This difference would be more significant when the baud rate is further increased since the overshooting time does not depend on the modulation rate. It should be noted that the interval between signals per symbol is 200 ps in Fig. 1 (b), which can be further decreased to less than 150 ps.

2.2 Experimental setup for generating an optical QAM signal

Figure 2 (a) shows an experimental setup for optical QAM. An external-cavity

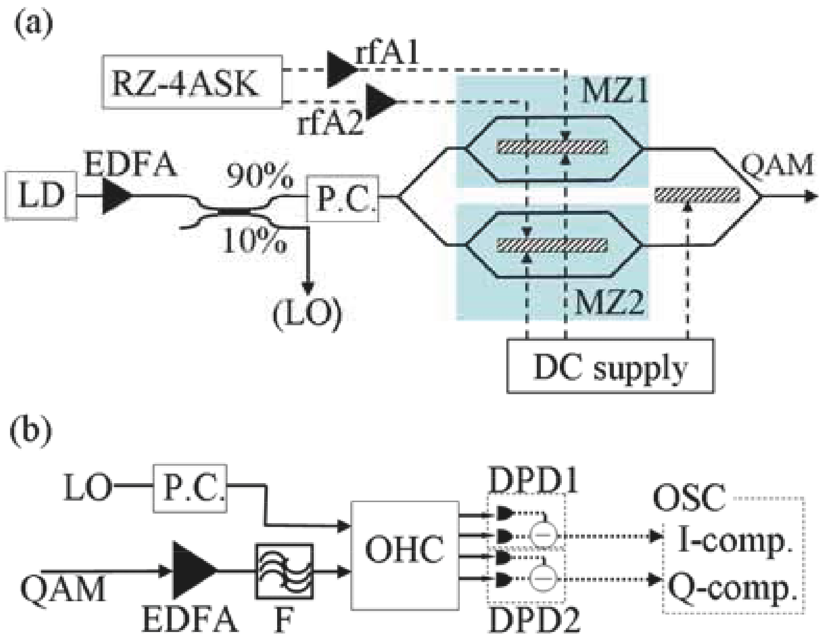

Fig. 2. Experimental setup for (a) generation and (b) demodulation of an optical QAM signal. LD: external-cavity laser diode; EDFA: erbium-doped optical fiber amplifier; P.C.: polarization controller; RZ-4ASK: two RZ-4ASK signal generators composed of an arbitrary waveform generator; rfA1, rfA2: rf amplifier; QAM: optical QAM signal; LO: local oscillator; F: optical bandpass filter; OHC: optical hybrid coupler; DPD1, DPD2: differential photodiode; OSC: digital oscilloscope. Solid lines and dashed lines indicate the flow of optical and electric signals, respectively.

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diode laser (power: 2.0 dBm, linewidth < 300 kHz, wavelength: 1570 nm) followed by an erbium-doped optical fiber amplifier (EDFA) was employed as the light source. After tapping 10% of its emission power for demodulation instead of a local oscillator, the remainder was launched into a conventional DPMZM which consists of a Mach-Zehnder (MZ) structure (MZ0) and two MZ structures (MZ1 and MZ2) nested in each arm of the MZ0. The half-wave voltages of MZ0, MZ1 and MZ2 are 7.0 V, 3.5 V and 3.3 V, respectively. The bias voltages of MZ1 and MZ2 were adjusted at their null-bias points. An optical n-level amplitude shift keying (n-ASK) signal was obtained by applying an electrical signal having n-levels in amplitude to the MZ structure. And the phase difference between the lightwaves passing through each nested MZ structure was adjusted to $\pi/2$ by controlling the bias voltage of MZ0 such that the optical output from the modulator was the vectorial-addition of two optical n-ASK signals, i.e., an optical n^2-QAM signal. In this experiment, we attempted to generate a 2-Gbaud, 16-level optical QAM signal from two 4-ASK electrical signals generated by an arbitrary waveform generator (Tektronics, AWG7102, 10 Gsamples/s) and rf amplifiers. The 4-ASK electrical signal was created from two pseudo-random bit sequences (period: $2^{15} - 1$) followed by one bit. Figure 2 (b) shows the demodulation system, which is composed of a pre-amplifier, an optical filter with a 0.6-nm bandwidth, an optical hybrid coupler and two balanced photodetectors. The output signals from the photodetectors were acquired by a digital oscilloscope (bandwidth: 4 GHz) instead of an analog/digital converter and correspond to the in-phase (I) component and quadrature (Q) component of an optical QAM signal. In this experiment, we adopted a digital carrier-phase estimation method to obtain a constellation map [7].

3 Evaluation of an optical QAM signal

Figure 3 shows the constellation map of the 12.0-dBm optical 16-QAM signal, obtained by the carrier-phase estimation method. As can be seen, each symbol of the 16-QAM signal is successfully separated by the method. By using an adaptive symbol discrimination method [8], bit-error rates (BERs) of the signal was evaluated as 1.04×10^{-3}, 8.60×10^{-4} and 9.47×10^{-4} for I-component, Q-component and whole demodulation signal, respectively. The values are less than the forward error correction (FEC) limit of 2×10^{-3}. In fact, the carrier-phase estimation method is optimized for optical QPSK signals, and so, the bit-error rate would be further decreased by adopting the advanced digital-coherent demodulation method [9].

4 Conclusion

In conclusion, we demonstrated 2-Gbaud optical QAM signal generation by adopting RZ electric signals for driving a DPMZM. By introducing zero intervals into the electric data signals, the pattering effect of the rf amplifiers was suppressed, which allowed precise control of the electric signal. With the help of an adaptive symbol discrimination method, demodulation of the

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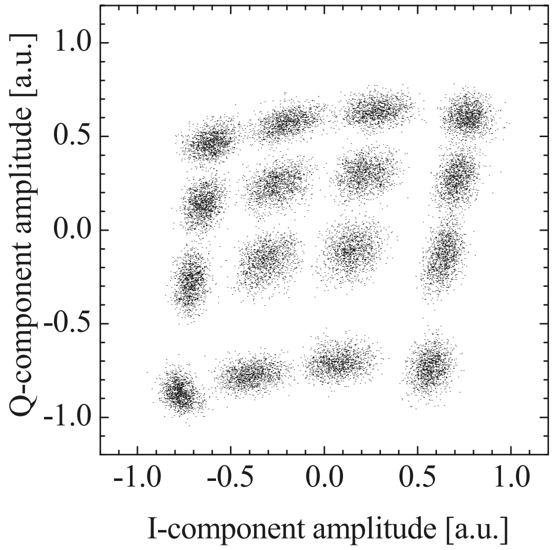

Fig. 3. Obtained constellation maps of an optical QAM signal after applying the carrier-phase estimation.

optical QAM signal was successful with a BER less than the FEC limit.

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