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Demonstration of optical quadrature amplitude modulation by using a high-speed optical DQPSK modulator and precise voltage-control technique

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Abstract We succeeded in observation of constellation map of a 16-level optical quadrature amplitude modulation with a rate of 2 Gbaud by adopting techniques of precise control of modulation voltages and digital carrier-phase estimation.

Multilevel optical modulation technology such as differential quadrature phase shift keying (DQPSK) and quadrature amplitude modulation (QAM) attracts much attention by favor of high-speed optical vectorial modulators [1, 2]. The most feature of these modulation techniques is that increase of data transportation rates can be possible without increase of modulation rates. Especially, optical QAM which is conventionally used in wireless communication technology is the most powerful tool based on the degree of state per one symbol and narrow modulation-data occupation in frequency domain. Nowadays, some proposals and experiments of the optical QAM [3, 4, 5] has been demonstrated though, optical phase locked loop (PLL) was employed in the experimental setup which limits increase in modulation rate of optical QAM per one symbol. In addition, a pilot carrier was used for optical PLL in the experimental setup [5]. Since the pilot carrier decreases effective spectral efficiency, development of alternative method is necessary for realization of high-modulation rate optical QAM. In this paper, we demonstrate 2.0G-baud 16-level optical QAM by a high-speed vectorial optical modulator. By adopting carrier-phase estimation technique [6] instead of rapid optical PLL, we succeeded in demodulation of optical QAM signal. Each levels in the constellation map obtained can be almost discriminated without consumption of frequency resource.

Figure 1 shows an experimental setup. Components enclosed by dashed (dotted) lines are for modulation (demodulation) of light signal. An external-cavity diode laser (Agilent, 8163A and 81689A) was used as a light source. The optical power was set at 6 dBm and was divided by a polarization-maintaining (PM) 50:50 optical directional coupler. Light emitted from one output port of the coupler was launched into an optical modulator while light emitted from the other port was lead to an input port of an optical hybrid coupler and was used as a local oscillator L_s for homodyne detection. After passing the modulator, the light was amplified by an EDFA (Fitel, ErFA1224-LN20-J) and passed through an optical narrowband filter (Ouyoukouden, TFMB-1560-1, $\Delta\lambda$ =1 nm).

Optical single side band modulator (Sumitomo Osaka Cement), which is a Mach-Zehnder (MZ) structure (MZ0) nesting two MZ structures (MZ1 and MZ2) in each arm of the MZ0, was used for modulating optical signal. Half wave voltages of MZ0, MZ1, MZ2 are 7.0 V, 3.5 V and 3.3 V, respectively. Bias voltage of MZ0 was set so as to ensure $\pi/2$ phase difference between each arm, while bias voltages of MZ1 and MZ2 were adjusted to be the minimum in light power transmittance of each MZ. Electric modulation signals corresponding to in-phase (I) component and quadrature-phase (Q) component were amplified (SHF, SHF806E, Bandwidth: 40 kHz – 42 GHz) and superimposed on the bias voltage of MZ1 and MZ2, respectively. The I component of the modu-

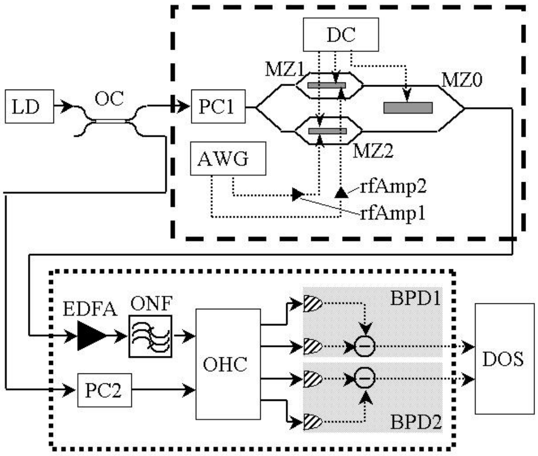

Fig.1 Experimental setup of an optical QAM system. Dashed bold square and dotted bold square indicate a part for modulation and demodulation, respectively. LD: External-cavity diode laser; OC: 50:50 optical coupler; PC1, PC2: polarization controller; EDFA: Erbium-doped optical amplifier; ONF: optical narrowband filter; OHC: optical 90-degree hybrid coupler; BPD1, BPD2: Balanced photodetector; AWG: Arbitrary waveform generator; rfAmp1, rfAmp2: rf signal amplifier; DC: DC power supply.

lation signal was created from a four-level data sequence made of two individual pseudo random bit sequences (period: 32767) followed by "0" and the Q component was created by 8192-point rotation of the I component data. These signals were generated by an arbitrary waveform generator (Tektronix, AWG7102) with a rate of 10 Gsamples/s, where the modulation speed was 2.0 Gbaud/s. One of difficulty in optical QAM is to generate rapid and precise multilevel electric signals applied to the optical modulator, which originates from a patterning effect of rf amplifiers. As this effect is one of hysterisis effect, we decreased input voltages of rf amplifiers to be nearly 0 V after each amplification of electric data signal. By using this technique, we achieved expansion of eye aperture of electric signal applying to the modulator.

We demodulated the optical data signal by using an optical 90-degree hybrid coupler (Optoplex, HB-C0AFCS001) and balanced detectors (u2t, BPDV2020R) and evaluated both I-component and Q-component of the modulation signal. The electric signals obtained by the balanced detection were acquired by a digital oscilloscope (Tektronix, TDS6154C) with a sampling rate of 10 Gsamples/s to construct a constellation map, after amplification by rf amplifiers (SHF, SHF200CP). Due to phase instability of the L_s, demodulation signals at each level were widely distributed in the obtained constellation map, which forces us to be difficult to discriminate their initial level. However, we succeeded in discrimination of each level in the constellation map, by using a digital synchronous process to eliminate the acquisition data during the level transition and a phase retrieval algorithm [6].

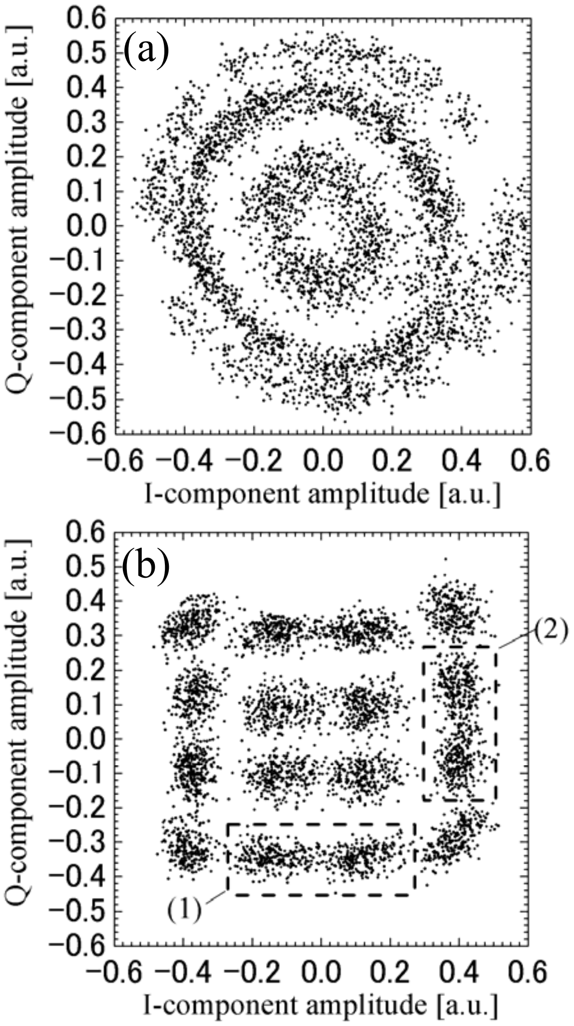

Fig.2 (a) An original constellation map obtained from the optical QAM system and (b) the constellation map after applying the phase-retrieval algorithm to the map (a).

Figure 2 shows constellation maps of demodulation signal. Figure 2(a) is the map before applying the phase retrieval process while Fig.2(b) is the map after applying the process to the obtained data shown in the Fig.2(a). From Fig.2(b), sixteen clusters of points can be confirmed by adopting the carrier-phase estimation algorithm. Q factor of the clusters in the dashed square (1) and (2) of Fig.2(b) are evaluated as 2.036 and 2.167 respectively, each of which corresponds to 12.2 dB and 12.7 dB in S/N ratio, respectively. It implies a possibility of the optical QAM with Gbaud-order modulation rate.

In conclusion, 2-Gbaud optical QAM is realized by using high-speed optical DQPSK modulator, precise control of electric signal and carrierphase estimation method. Each level can be discriminated by adopting carrier phase estimation algorithm instead of optical PLL.

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