Generation of 64-QAM Signals Using a Single Dual-Drive IQ Modulator Driven by 4-level and Binary Electrical Signals

Shuangyi Yan[1], Dawei Wang[1], Yuliang Gao[2], Chao Lu[1], Alan Pak Tao Lau[2], Yupeng Zhu[1], Yongheng Dai[3] and Xiaogeng Xu[3]

[1]*Photonics Research Center, Department of Electronic and Information Engineering, The Hong Kong Polytechnic University, Hong Kong*
[2]*Photonics Research Center, Department of Electrical Engineering, The Hong Kong Polytechnic University, Hong Kong*
[3]*Huawei Technologies Co., Ltd., Shenzhen, P.R. China*
nechoyan@gmail.com

Abstract: A simple square 64-QAM generation technique using a commercially available dual-drive IQ modulator driven by 4-level and binary electrical signals is proposed. Polarization multiplexed (PM) 64-QAM signals at 20Gbaud/s are experimentally demonstrated.
OCIS codes: (060.5060) Phase modulation; (060.1660) Coherent communications; (060.2330) Fiber optics communications;

1. Introduction

Optical transport networks have been evolving continuously to deliver more than 100Gbit/s per channel in response to the sharp increase of the network capacity demand. Coherent detection technologies with high order modulation format such as 16-QAM have become the potential candidate to realize 400Gb/s per channel transmission. For the next target bit rate of 1Tbit/s per channel, most of the research interests focus on the combination of many carriers to form a ‘super channel’ using CO-OFDM or Nyquist WDM [1-2]. High spectral-efficiency formats such as 64-QAM at high baud rate are essential to reduce the number of carriers.

Unfortunately, generating 64-QAM signals at tens of Gbaud/s is no easy task, not to mention the practicality aspects of such generation techniques. 64-QAM signals can be generated using an integrated complex optical modulator in parallel structure [3], or in serial structure [4]. However, the complex structures of the 64-QAM modulators make them difficult to fabricate and they are far from commercially available. Another more common method to generate 64-QAM signals is to drive a single-drive IQ modulator with eight-level electrical signals. This can be achieved by using digital-to-analog converters (DAC) [5], electrical-optical-electrical (E-O-E) method [6], high power 3-bit DACs [7], or electrical resistive components such as combiners and attenuators [8]. Compared with typical binary signals or four-level driving signals used in 16-QAM transmitters, eight-level signals are more sensitive to intensity noises which can be introduced by impedance mismatches, signal reflections, etc. When the baud rate increases, obtain high quality eight-level electrical driving signals become much more challenging.

In this paper, we propose and experimentally demonstrated a 20 Gbaud/s square polarization multiplexed (PM)-64-QAM transmitter using a commercially available dual-drive IQ modulator driven by four-level signals and binary signals. The reduced number of driving signal levels renders this technique more practical and easier to be realized in a high baud rate transmitter.

2. Operating Principle

The operating principle of the proposed 64-QAM transmitter is shown in Fig. 1. A commercially available dual-drive nested IQ modulator is used as the external modulator. Each MZM in the dual-drive IQ modulator is a dual-drive MZM (DD-MZM), driven by a four-level signal and a binary signal for each RF input port as shown in Fig. 1(a). As a result, two independent eight-level amplitude- and phase-shift keying (8-APSK) signals are synthesized to modulate the *I* and *Q* components of the optical carrier. Then the 64-QAM signal is generated by adding the *I* and *Q* components together.

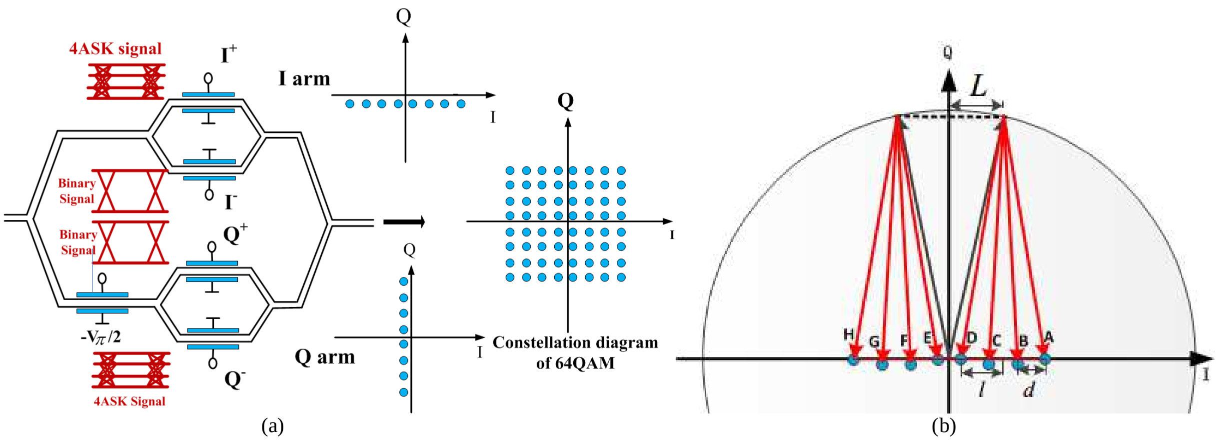


Fig. 1 Operation principle of the proposed 64-QAM transmitter using dual-drive IQ modulator driven by four-level and binary signals. (a) 64-QAM generation with IQ modulator; (b) Phasor representation for 8-APSK generation with DD-MZM.

The phasor representation for the 8-APSK generation in the *I*-arm of the IQ modulator is shown in Fig. 1(b). The DD-MZM is operated in push-pull mode and biased at the null point. Binary signals with amplitude V_{Bin} and four-level signals are used to drive the DD-MZM. The four-level signals can be obtained by combining two binary signals with different amplitudes denoted as V_H and V_L with $V_H > V_L$. For square 64-QAM generation, eight equidistant signal points on the constellation diagram should be generated in parallel with the *I*- or *Q*-axis. Under our proposed transmitter configuration, the eight signal points generated do not exactly stay in a line. Rather, each four of them lies on a circle. Nonetheless, we can neglect any penalty resulting from such deviation from the ideal constellation when the driving signals are considerably smaller than the half-wave voltage V_π. Simulation results show that the driving signals chosen in our experiments will induce a < 1 dB penalty compared with the standard square 64-QAM constellation. Alternatively, optimal decision boundaries based on maximum likelihood or other metrics can be used to improve detection performance [9-10]. In this case, the driving amplitude requirements for 64-QAM signal generation can be graphically represented in Fig. 1(b) as *l=1.5d*, and *L=2d*. These requirements can be analytically expressed as

$$\sin\left(\frac{V_H + V_L}{2V_\pi}\right) = 3\sin\left(\frac{V_H - V_L}{2V_\pi}\right) \text{and } \sin\left(\frac{V_{Bin}}{2V_\pi}\right) = 6\sin\left(\frac{V_H - V_L}{2V_\pi}\right). \tag{1}$$

For small driving signals, such requirements can simply be written as $V_{Bin} = 4V_L$ and $V_H = 2V_L$. In this case, eight constellation points along the *I*-axis can be obtained in the I-arm of the IQ modulator as shown in Fig. 1(b). Similarly, eight constellation points can also be obtained along the Q-axis and the overall 64-QAM signal can be generated by adding two 8-APSK signals in the *I* and *Q*-arms.

3. Experimental Results

Fig. 2 shows the experimental setup for the proposed 64-QAM signal generation technique. An external cavity laser (ECL) with about 100 kHz linewidth is used as the transmitter and the local oscillator. The dual-drive IQ modulator (FTM79600Ex, from Fujistu) is driven by two 4-level electrical signals and two binary electrical signals. The 20Gbit/s binary signals are obtained by multiplexing two 10 Gbit/s data streams. The four-level electrical signals are generated with a 4-level signal generator by feeding two 20 Gbit/s electrical data streams. All the driving signals are de-correlated with each other by introducing 1 ns extra delay. The amplitudes of the driving signals are adjusted according to equation (1). The generated 20Gbaud/s 64-QAM signals are amplified by an EDFA and are then launched into a PDM emulator, which consists of a polarization controller, polarization beam splitter/combiner (PBS/PBC) and an optical delay line, to realize PM-64-QAM. Different amounts of ASE noise are loaded to the signals to realized different OSNR values.

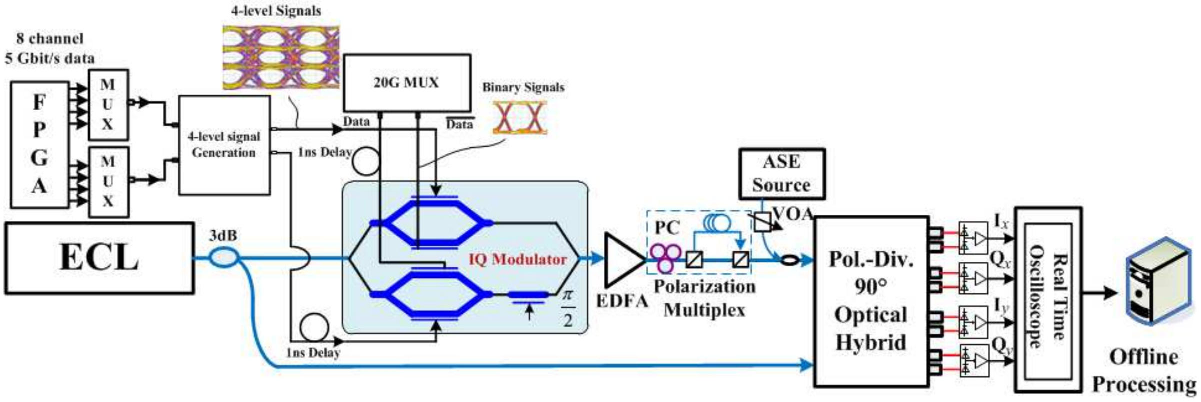
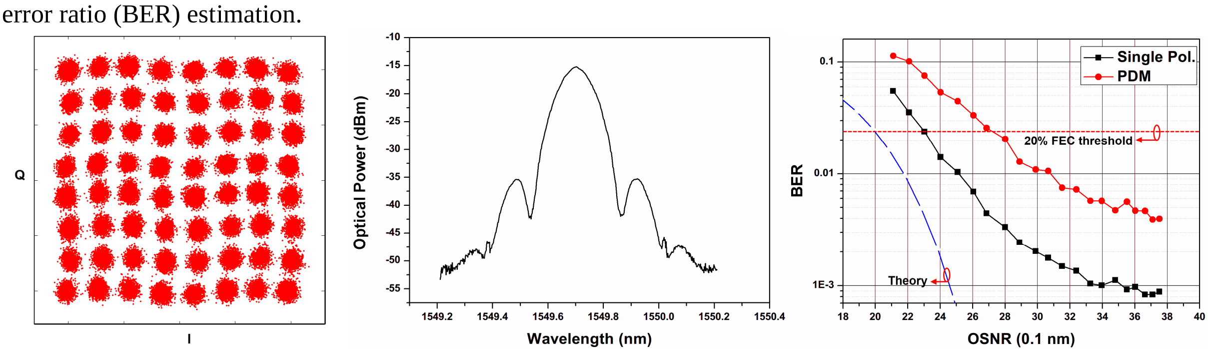


Fig. 2 Experimental setup for the proposed 64-QAM signal generation technique. Binary electrical signals and 4-level electrical signals are used to drive the dual-drive IQ modulator

On the receiver side, the signals are coherently detected with a polarization-diversity receiver. Part of the CW light of the transmitter ECL is used as the local oscillator, thus realizing self-homodyne detection. The electrical signals are then sampled for analog-to-digital (A/D) conversion using a real-time oscilloscope (16GHz bandwidth, 50Gs/s sampling rate) and processed offline to perform normalization, polarization de-multiplexing, carrier phase estimation [11], 681-tap LMS filter for performance optimization followed by standard symbol detection and bit-error ratio (BER) estimation.



(a) (b) (c)

Fig. 3 (a) Received signal distribution for the proposed 64-QAM generator; (b) corresponding optical spectrum. (c) Back-to-back BER vs. OSNR using the proposed 64-QAM generation technique.

Fig. 3 shows the received signal distributions and the corresponding optical spectrum of the 64-QAM signals with an OSNR (in 0.1 nm) of 38dB. The 20dB bandwidth of the 64-QAM signal is about 0.28nm. The back-to-back performance of the proposed 64-QAM generation technique is investigated and Fig. 3(c) shows the BER vs. OSNR obtained from our experimental setup. The required OSNR to achieve BER = 2.4E-2 (20% SD-FEC threshold) is about 27 dB using our proposed 64-QAM generation technique. It should be noted that required OSNR can be further reduced with higher bandwidth and low-noise real-time sampling scope.

4. Conclusions

We demonstrated a simple 64-QAM signal generation technique using four-level and binary electrical signals to drive a dual-drive IQ modulator. Experimental results for a 20 Gsymbols/s (240Gbit/s) system demonstrated the technique's feasibility and potential as a simpler and more practical 64-QAM transmitter in future coherent communication links.

[1] X. Liu et al., paper p. Th.13.B.1, ECOC 2011.
[2] X. Zhou et al., paper p.PDPB9, OFC 2010.
[3] H. Yamazaki, T. Yamada, T. Goh, Y. Sakamaki, and A. Kaneko, paper 2.2.1, ECOC 2009.
[4] E. Yossef, O. Amrani, and S. Ruschin, J LIGHTWAVE TECHNOL, 29(17), 2545–2551 (2011).
[5] R. Schmogrow et al., IEEE PHOTONIC TECH L, 22(21), 1601–1603 (2010).
[6] J. Yu, X. Zhou, S. Gupta, Y. Huang, and M. Huang, IEEE PHOTONIC TECH L, 22(2), 115–117 (2010).
[7] A. H. Gnauck et al., paper PDPB2, NFOEC, 2011.
[8] W. Peng, H. Takahashi, T. Tsuritani, and M. Itsuro, paper PDP1-3, OECC 2012.
[9] A. Bernardini and S. De Fina, IEEE Trans Neural Netw, 9(2), 241 –246 (1998).
[10] A. P. T. Lau and J. M. Kahn, J LIGHTWAVE TECHNOL, 25(10), 3008 –3016 (2007).
[11] T. Pfau, S. Hoffmann, and R. Noe, J LIGHTWAVE TECHNOL, 27(8), 989–999 (2009).