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

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Abstract: A simple square 64-QAM generation technique using a commercially available dual-drive IQ modulator driven by four-level and binary electrical signals is proposed. Polarization multiplexed (PM) 64-QAM signals at 20Gbaud/s are experimentally demonstrated.

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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 $V_\pi$. 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

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

(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 Fujitsu) 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 demultiplexing, carrier phase estimation [11], 681-tap LMS filter for performance optimization followed by standard symbol detection and bit-error ratio (BER) estimation.

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.