Generation of 432Gb/s Single-carrier Optical Signal by Format Conversion from QPSK to 16QAM

Jianjun Yu[1,2], Ze Dong[2,3], Xianfeng Tang[2,3], Wei Jian[2,3], Yan Xia[2], Sheping Shi[2], Shu-Hao Fan[3] and Gee-Kung Chang[3]

1) ZTE USA INC, Iselin, NJ 08830, USA (yu.jianjun@zteusa.com)
2) ZTE Corp. Beijing, 100876, China (yu.jianjun@zte.com.cn)
3) The School of ECE, Georgia Institute of Technology, GA 30332, USA

Abstract: We have proposed and experimentally demonstrated the generation of 432Gb/s (54Gbaud PM-16QAM) single-carrier optical signal by format conversion from QPSK to 16QAM.

OCIS codes: (060. 2330) Fiber optical communications; (060.2360) Fiber optics links and subsystems

1. Introduction

400 Gb/s per single channel is expected to be a possible data rate for long-haul (LH) optical transmission beyond 100 GbE [1-8]. However, due to the bandwidth limitation of existing electrical or optical components, it is quite a challenge job to generate 400Gbit/s signal on a single carrier [2, 3]. These techniques to generate 400Gbit/s signal require high-quality ultra-short pulses and multiple modulators, maintaining orthogonality among subcarriers in the presence of phase noise or good linear performance for both optical and electrical components, which makes the transmitters complicated [2-4]. In this paper, we demonstrate a novel scheme for the generation of 432-Gb/s polarization multiplexing (PM)-16QAM optical signal by modulation format conversion from QPSK to 16QAM. The 432-Gb/s (the net bit rate is 403.7Gb/s after 7% FEC overhead is removed) signal with PM 16-QAM modulation is generated by only cascading one I/Q modulator and one single-arm MZM. At the transmitter side, the CW lightwave is modulated by an integrated regular I/Q modulator driven by two binary electrical signals after special coding to generate optical QPSK signal, then an electrical clock with the same frequency of the binary signal is used to drive an MZM intensity modulator (IM) to carve the optical QPSK signal. Different from the regular pulse carve for pure QPSK signal generation, the clock signal in the scheme properly carves the transition position of QPSK signal for optical 16-QAM signal. At the receiver side, the optical 16-QAM signal is coherently detected and retrieved via off-line DSP process, in which the modulus recovery is implemented based on the enhanced three-modulus CMA algorithm; the estimation of the frequency offset and phase recovery are processed by the M-th power and the maximum likelihood sequence estimation (MLSE), respectively [8].

2. Principle of Optical 16QAM Generation

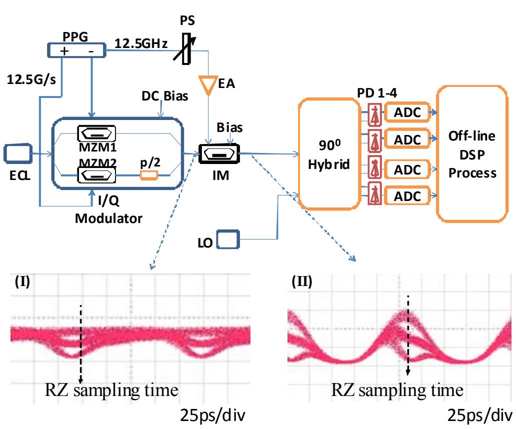


Fig. 1. 16QAM optical signal generation.

The operational principle of the proposed scheme is shown in Fig 1. The 16-QAM transmitter consists of a parallel 'I/Q' modulator driven by two binary data. The phase difference between the upper and the lower branch in the parallel 'I/Q' modulator is set to be $\pi/2$and biased at the null point for MZM1 and MZM2 respectively, serving as two zero-chirp $0/\pi$ phase modulators. As an example for the illustration, the waveform after the I/Q modulator is shown in Fig.1 as inset (I). If the bit rate of binary data (data 1 or data 2) is x Gb/s (12.5Gb/s in the example in Fig. 1), x GHz (12.5GHz in Fig. 1) clock signal should be used to drive the cascade intensity modulator (IM). In the scheme, the IM is used to carve the signal at the transit position of the symbols to generate optical 16-QAM. Then the 16-QAM optical signal is detected by a coherent receiver with post off-line DSP. It is also important to point out that the data 1 or 2 driving MZM1 and MZM2 should be encoded by a special way in order to generate optical 16-QAM signal. Here we show how to code the binary data in Fig. 2. Fig. 2 (a) is a regular BPSK data encoded as "1" and "0". It is well known that there exist rise and fall transit when the signal is changed from "1" to "0" or from "0" to "1" in binary signal due to the limited bandwidth of the components. In the scheme, the two states of "fall transit" and "rise transit" are utilized to realize the transit coding after proper pulse carve. Fig. 2 (b) shows the new data after carved coding.

Different from the regular case as shown in Fig. 2(a), the time for judging the data in Fig. 2(b) is shifted to the transit position. Here we assume that the rise edge is "10" and fall edge is "01". If the signal is high-level and maintained in one bit slot, it is encoded as "00", similarly, the low-level maintained in one bit slot is coded as "11". We can use RZ pulse to carve the signal at the transit position and realize the time sampling at the right position. When the I/Q modulator is driven by I and Q data, 16-QAM optical signal can be generated as shown in Fig. 2(c). The measured optical spectrum of 12.5-Gbaud optical signal is shown in Fig. 3 as an example. 16-QAM optical signal has wider spectrum due to the broadened RZ pulse shape. The constellations for QPSK (without IM) and 16-QAM (transit carve from QPSK) are shown in Fig. 3. The measured BER is shown in Fig. 2(d).

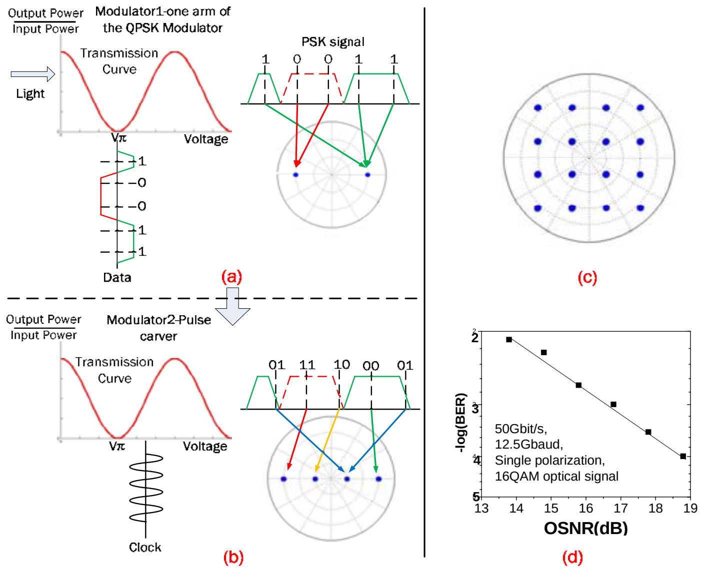


Fig. 2

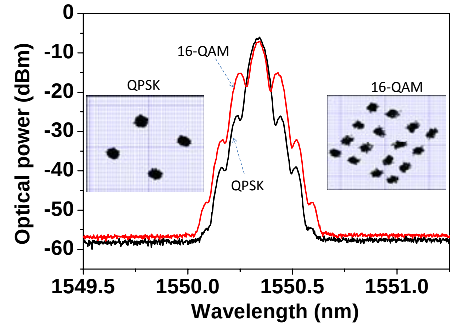


Fig.3

Fig.2. 16QAM optical signal generation. (a)Two level, (b) four-level, (c) 16QAM, (d)BER of 50Gb/s, 12.5Gbaud, RZ-16QAM optical signal. Fig. 3. The measured optical spectrum and constellation for 50Gb/s (12.5Gbaud 16QAM, single polarization) signals. Constellation (a) QPSK signal (without IM), (b) 16QAM.

3. Experimental Setup and Results

The experiment setup for the generation of 432-Gb/s optical 16-QAM signals and the corresponding coherent receiver are shown in Fig. 4. The 3-dB bandwidth of the integrated MZM (I/Q modulator) and the single-arm intensity modulator (IM) are 34 GHz and 37 GHz, respectively. The 54Gbaud QPSK signal is generated via an I/Q modulator driven by two 54Gb/s synchronized non-return-to-zero (NRZ) electrical signals. The 54Gb/s electrical signals are generated by multiplexing four delay-decorrelated copies of a 13.5Gb/s true pseudo-random bit sequence (PRBS) of length 2^{15}-1. The eye diagram of QPSK signal (direct detection and before IM modulator) is shown in Fig. 4(I).The generated optical QPSK is carved by the cascaded IM, which is driven by 54-GHz clock generated by a frequency doubler. A phase shifter (PS) is used to adjust the phase of the clock. By carving the transit edge of the optical QPSK, optical 16-QAM signal is generated and the waveform is shown in Fig. 4(II). Fig. 4(III) shows the measured optical spectrum of the optical QPSK and 16-QAM signals. The polarization multiplexing is achieved by dividing and recombining the signal with 320 symbol delay before a polarization beam combiner. An external cavity laser (with the line-width ≤100kHz) is employed as the LO laser. After the 2×8 ports 90 degree hybrid, the signal is converted to electrical signals via four balance detectors. The high-speed A/D conversion is realized by two 2-channel 80GSa/s real-time scopes with 30GHz bandwidths. The two scopes are triggered by high-speed signal to capture the same time window on both scopes [9].

The digital signals after A/D converters are collected and calculated through off-line digital signal processing (DSP). Firstly, the clock is extracted by using "square and filter" method. The digital signal will be re-sampled to twice-baud rate using the recovery clock. the classic first-order CMA at the initial equalization stage for pre-convergence is utilized to increase the convergence speed and the robustness of blind modulus algorithm recovery [3, 7]. Then the two complex-valued, 13-tap, T/2-spaced adaptive FIR filters, optimized by the cascade three-modulus algorithm, are used to retrieve the three modulus of 16-QAM. The error ε can be expressed as: $\varepsilon = \mathrm{abs}(||Z| - A_1| - A_2) - A_3$, Z is the output of the CMA FIR filter, A_1=0.5(R_1+R_2), A_2=0.5(R_3-R_1),

A_3=0.5(R_3-R_2) are the three convergence modulus for 16-QAM signals. The carrier recovery is performed in the subsequent step where the feed-forward 4-th power algorithm (only the points located in the inner circle are selected) is used to estimate the frequency offset between the LO and the received optical signal carrier, and then the MLSE algorithm is utilized to estimate the carrier phase rotation according to the constellation of the ideal 16-QAM. The constellation of retrieved 16-QAM signal is shown as an inset in Fig. 4. We measure the BER performance of 432-Gb/s PM-16QAM optical signal by counting over 1 million bits of information. The constellation for X and Y polarization is shown in Fig. 4(iv). The measured BER is 9e-4 (X pol.) and 1e-3 (Y pol).

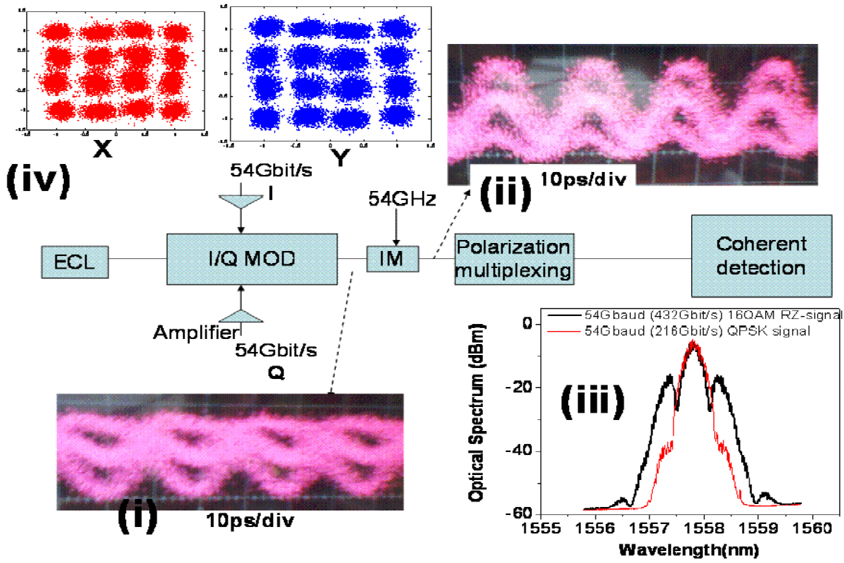
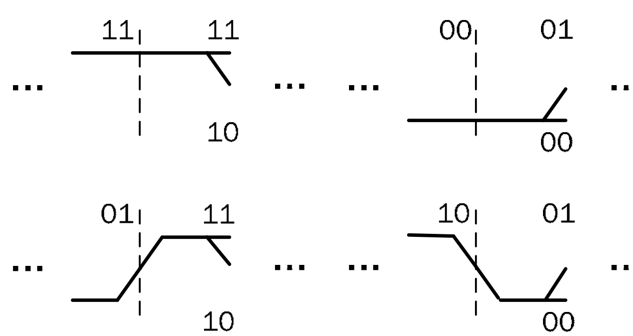


Fig. 4: Experimental setup for 432Gbit/s PM-16QAM optical signal generation and receiving.

4. Discussion

As this scheme adopts a special coding method, data cannot be directly used to drive the I/Q modulator. Fig. 5 shows the requirement of the data to drive one arm of the modulator. If the current data is '11', the following data should be '11' or '10'; '00' and '01' cannot be coded. It is a challenge to precode the data to realize this special coding scheme, and researches on it are still being done. However, signals generated in this simple manner can be used in the investigation into the performance of the high-speed 16QAM signals either in back-to-back or long-distance systems.



FFig. 5. The required data for the transit edge coding method.

5. Conclusion

We have experimentally demonstrated a novel scheme generating 432-Gb/s (without using OFDM or OTDM) PM-16QAM single carrier optical signal. The measured BER for the 432-Gb/s signal is smaller than $2x10^{-3}$ (FEC limitation). The proposed scheme significantly reduces the bandwidth of optical and electrical components based on a novel coding technique while keeps a simple architecture.

Acknowledgement

The work is partly supported by China "863" projector under the contract number of "2009AA01Z221".

Reference

[1] A. H. Gnauck, et al, OFC 2010, PDPB8.
[2] X. Liu, et al, OFC 2010, PDPC2.
[3] J. Yu, et al, Opt. Express 17, 17928-17933 (2009).
[4] P. Winzer, ECOC 2010, PD. 2.2..
[5] T. Sakamoto et al., in *Proc. ECOC 2008,* paper Tu.1.E.3.
[6] R. Dischler, et al., OFC 2009, PDP2.
[7] A. Sano et al., in *Proc. OFC 2010,* paper. PDPB 7.
[8] X. Zhou et al., in *Proc. ECOC 2009,* Paper 10.3.5.
[9] P. J. Winzer, ECOC 2009, PD 2.7.