Generations of Multiple 16QAM signals at 40Gbit/s using a multi-format transmitter

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We propose a scheme for generating multiple 16QAM signals at 40Gbit/s using a novel transmitter. The scheme is based on a dual-parallel Mach–Zehnder modulator (DPMZM) followed by a phase modulator (PM). Three types of 16QAM signals are obtained using the proposed transmitter by adjusting the amplitudes of the electrical drive signals and bias voltages of the modulators. In order to further investigate the transmission performance, the generated 16QAM signals are transmitted through an 80-km standard single-mode fiber (SSMF) and detected by a coherent receiver, error free performance is achieved.

***Index Terms*—Optical fiber communication, Optical transmitters, Optical modulation, 16QAM signals**

I. INTRODUCTION

With the drive of ever-increasing Internet traffic, efficient use of signal bandwidth has become a key technology to increase the transmission capacity over already installed optical fibres and amplifiers. However, a binary signal beyond 40Gbit/s is severely limited by the operating speed of electrical and optical components, and also by the rapidly reducing chromatic dispersion (CD) and the polarization mode dispersion (PMD) tolerance [1]. On the other hand, multi-level modulation formats combined with coherent detection have become a promising technology to increase the capacity of optical fibre transmission and also to extend transmission distance [1-4]. Among multi-level modulation formats, 16 quadrature amplitude modulation (QAM), which carries four bits per symbol, is an attractive candidate. With respect to the constellation distributions, 16QAM can be categorized to three groups: square-16QAM, star-16QAM and 16APSK (amplitude phase shift key). Recently, square-16QAM has been extensively investigated and multiple schemes have been proposed and experimentally demonstrated [5][6]. Compared with square-16QAM, few research works are on the generations of star-16QAM and 16APSK signal. Moreover, the previously proposed transmitters of 16QAM could be complicated and output only one format.

In this paper, for the first time to the best of our knowledge, we propose a novel scheme for a 40Gbit/s 16QAM transmitter, which can generate various 16QAM signals. The feasibility of proposed transmitter is verified by simulations. Furthermore, the generated 16QAM signals are transmitted through an 80-km transmission line. Coherent detection is performed after the transmission link. Clear constellation diagrams and error free performance are achieved.

II. PRINCIPLE

A. Star-16QAM

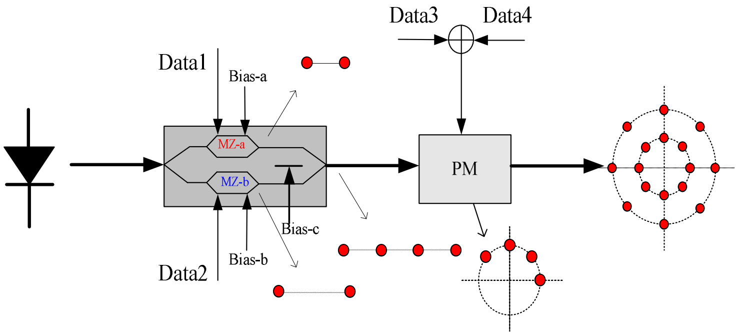

Fig.1. Schematic diagram of star-16QAM

The schematic diagram of the proposed transmitter is depicted in Fig.1, which consists of a DPMZM followed by a PM. The DPMZM comprises a pair of x-cut $LiNbO_3$ MZMs (MZMA, MZMB) embedded in the two arms of a main MZM structure. The two sub-MZMs have the same structure and performance, and the main MZM superimposes the outputs of the two sub-MZMs. The structure of the transmitter can be divided into two stages. In the first stage, the continuous wave is 4APSK modulated by a DPMZM. In particular, two submodulators of the DPMZM are biased at null point and driven by 10-Gbit/s Data1 and Data2, respectively, to generate two BPSK signals with unequal amplitudes. The two BPSK signals are then constructively interfered by adjusting Bias-c such that a 4APSK signal can be obtained, as depicted in Fig. 1. In the second stage, the generated 4APSK signal is further phase-modulated by a 4-level electrical signal, which is obtained by combining Data3 and Data4 at 10Gbit/s, to realize 4-PSK (0, π/4, π/2, 3π/4) modulation .In that case, a star-16QAM signal is achieved.

B. Square-16QAM

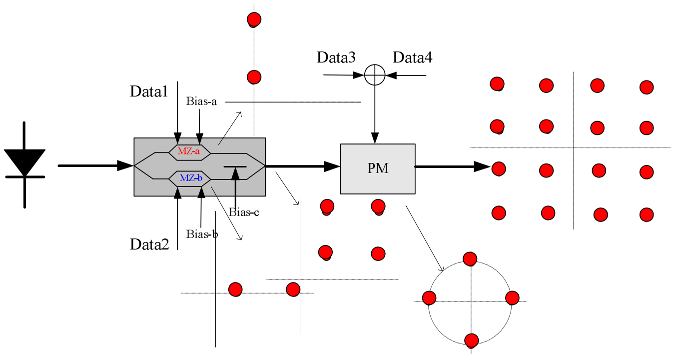

Fig.2. Schematic diagram of square-16QAM

To obtain a square-16QAM signal, we only need to adjust the amplitudes of electrical signals and adjust the biases of modulators, while the stucture of the transmitter remains unchanged. The schematic diagram is shown in Fig.2. In the first stage, both sub-MZMs of the DPMZM are biased at quadrature point and driven by Data1 and Data2 with the same amplitude to generate two 2ASK signals with equal extinction ratio (ER). By adjusting the bias of main MZM, the two ASK signals achieve a 90° phase difference and then are combined to obtain an offset QPSK signal with its origin biased at first quadrant, as depicted in Fig. 2. In the second stage, the generated offset QPSK signal is further QPSK modulated by a PM, which is driven by 4-level electrical signal to realize a star-16QAM signal.

C. 16APSK

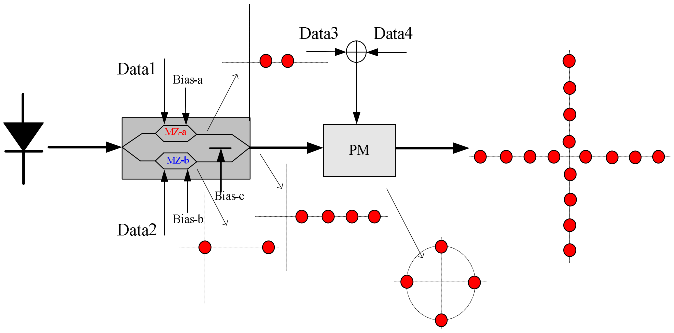

Fig.3. Schematic diagram of 16APSK

Some adjustments on the amplitudes of electrical signals and the biases of DPMZM are required to achieve 16APSK modulation. In particular, MZM-a of the DPMZM is biased at quadrature point and driven by Data1 at 10Gbit/s to generate 2ASK with finite ER. MZM-b of the DPMZM is also biased at quadrature point and driven by Data2 at 10Gbit/s to produce 2ASK with infinite ER. The two optical signals are then interfered constructively by adjusting the bias of the main MZM, a 4-ASK signal is realized. The PM, which is driven by a 4-level electrical signal generated by combining Data3 and Data4 at 10Gbit/s, further QPSK-modulates the generated 4-ASK signal to obtain a 16APSK signal.

III. SIMULATION AND RESULTS

To show the feasibility of proposed transmitter and investigate the transmission performance, we perform a simulation with its setup depicted in Fig. 4, using VPI TransmissionMaker. At the transmitter, a distributed feedback (DFB) laser with a linewidth of 1 MHz is used as continuous wave (CW) light source, which is modulated by the transmitter to produce 40-Gbit/s star-16QAM signal. The output of the transmitter is 0dBm after being amplified by an erbium-doped fibre amplifier (EDFA) and filtered by a tunable bandpass filter (BPF) with a bandwidth of 1.6 nm. At the receiver, coherent detection is performed. Another DFB with the same frequency and phase is used as local oscillator (LO),

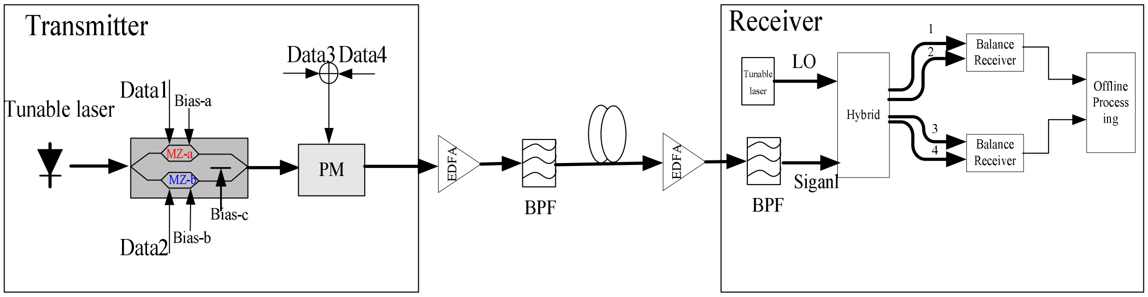

Fig.4 Setup of the proposed scheme

which is mixed with the received star-16QAM signal in an optical 90-degree hybrid. The outputs of hybrid are detected by two balanced detectors (BD) with the same performance. The real and imaginary parts of the star-16QAM signal are obtained by simultaneously sampling the outputs of the receivers. The sampled data are then processed off-line, which is realized using MATLAB program, including resampling, carrier phase estimation, and constellation recovery. 16384 bits are sampled in the system. The back-to-back (BTB) eye diagram and constellation map of star-16QAM are shown in Fig.5 (a) and (b), respectively. After transmission through an 80-km standard single-mode fiber (SSMF), the signal is boosted by another EDFA to 2 dBm. A 16-km dispersion compensating fiber (DCF) is used to compensate CD accumulated through the transmission link. The SSMF has a dispersion $D\psi=$ 16ps/(nm$\le$km), a dispersion slope $S\psi=$ 0▷06 ps/(nm$^2\le$km), a nonlinear index $\gamma\ \psi=$ 1▷31W$^{\nwarrow 1}$/km, and a loss $\alpha\ \psi=$0▷2dB/km. The DCF parameters are $D\psi=$ • 80 ps/(nm$\le$km), $S\psi=$ • 0▷18 ps/(nm$^2\le$km), ψ $\gamma =$ 2▷64W$^{\nwarrow 1}$/km, and $\alpha =$ 0▷6dB/km, respectively.

The signal is boosted to 0 dBm and then coherently detected in the receiver. It is shown that after 80-km transmission, the eye diagram and constellation map of star-16QAM are still clear enough to enable error-free operation, as depicted in Fig.6 (a) and (b), respectively.

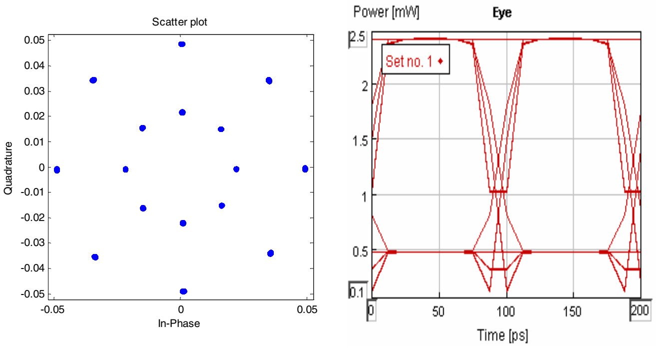

Fig.5 BTB constellation map (a) and eye diagram (b) of star-16QAM.

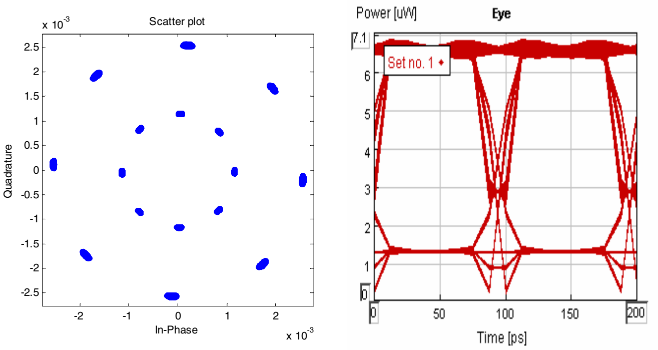

Fig.6 Constellation map (a) and eye diagram (b) of star-16QAM after 80-km transmission

By adjusting the amplitudes of electrical signals and biases of DPMZM in the transmitter, we obtain square-16QAM signal, which is also transmitted through the mentioned link. After coherent detection and off-line processing, clear eye diagrams and constellation maps in the conditions of BTB and after 80-km transmission are achieved, shown in Fig.7 and Fig.8, respectively.

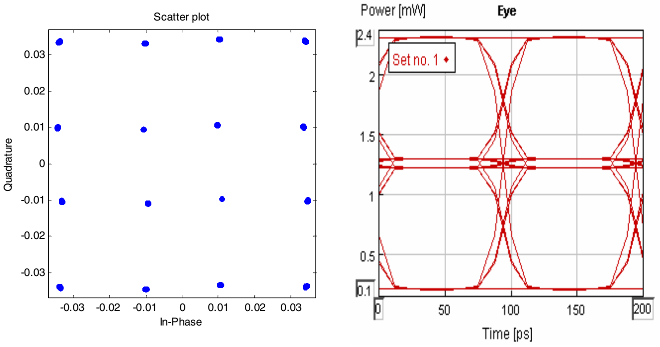

Fig.7 BTB constellation map (a) and eye diagram (b) of square-16QAM

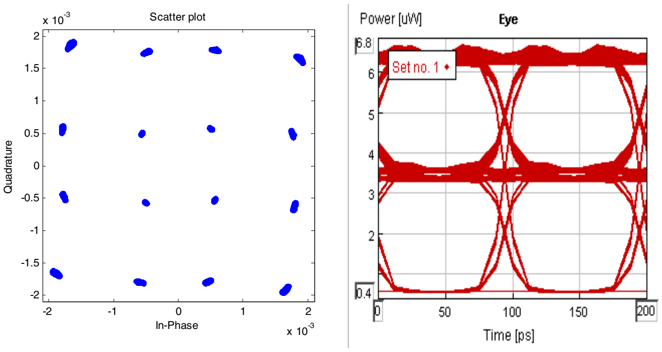

Fig.8 Constellation map (a) and eye diagram (b) of square-16QAM after 80-km transmission.

16APSK can also be obtained with some modifications on the transmitter. Coherent detection and off-line processing are performed on the received 16APSK signal and clear eyes and constellation are obtained, with their diagrams in Fig.9 and Fig.10.

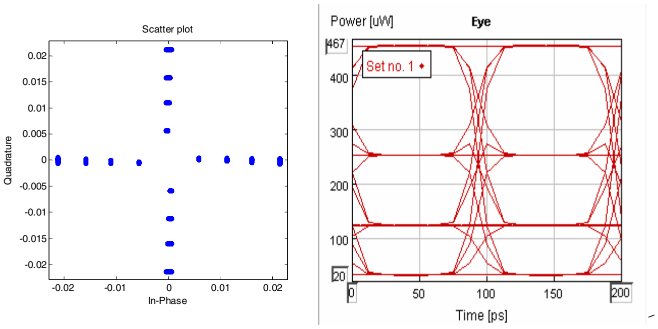

Fig.9 BTB constellation map (a) and eye diagram (b) of 16APSK.

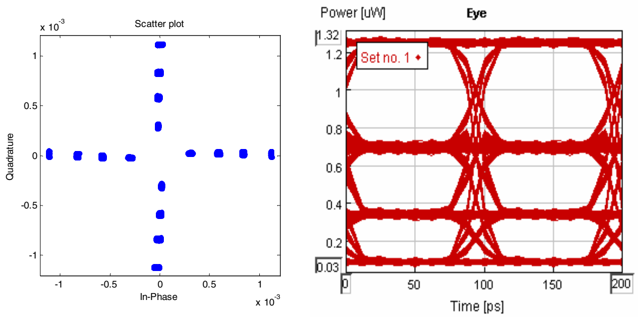

Fig.10 Constellation map (a) and eye diagram (b) of 16APSK after 80-km transmission.

IV. CONCLUSION

We have proposed a novel transmitter based on DPMZM and a following PM. Star-16QAM, square-16QAM and 16APSK are realized by VPI TransmissionMaker and thus the feasibility of the proposed transmitter is proved. The signals are also transmitted through an 80-km SSMF and detected by a coherent receiver. Clear eye diagrams and constellation maps are obtained and error performance is verified.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

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