M-PSK Versatile Modulation using a Single-electrode Straight-line Phase Modulator and Digital Signal Processing for ISI-suppression

Moriya Nakamura, Yukiyoshi Kamio, and Tetsuya Miyazaki
National Institute of Information and Communications Technology (NICT)
4-2-1, Nukui-Kitamachi, Koganei, Tokyo 184-8795, Japan, E-mail: m-naka@nict.go.jp

Abstract: BPSK, QPSK, and 8-PSK modulation/demodulation was experimentally demonstrated using only a single-electrode straight-line phase modulator for the first time. ISI caused by the modulation was compensated by pre-equalization based on digital signal processing, achieving BER<10^{-9}.

OCIS codes: (060.1660) Coherent communications; (060.2330) Fiber optics communications

1. Introduction

Multi-level modulation is an important technique used to enhance spectral efficiency and increase data transmission speed without the need for higher electrical bandwidth. In particular, M-ary phase-shift keying (PSK), including 8-ary PSK (8-PSK), is regarded as one of the most attractive modulation techniques because of its high nonlinear tolerance due to the constant power envelope of the modulated signal. However, experimental demonstrations of 8-PSK modulation have been complicated, involving using a number of connected modulators driven by binary electrical signals [1-5]. The modulators had to be driven by binary signals to suppress inter-symbol interference (ISI) caused by the limited frequency bandwidth of electrical components, such as optical modulators and driver amplifiers [6]. One method involves using three tandem phase modulators (PMs), as depicted in Fig. 1(a), in which π, $\pi/2$, and $\pi/4$ phase modulations are performed individually [1-2]. Some papers have reported experimental studies using cascaded connection of an in-phase/quadrature-phase (IQ) modulator for quadrature phase-shift keying (QPSK) modulation and a PM for $\pi/4$ phase modulation, as shown in Fig. 1(b) [3-4]. Recently, another method using a quad-parallel Mach-Zehnder (MZ) modulator, which can be depicted by parallel IQ modulators as shown in Fig. 1(c), was also demonstrated [5]. It has been theoretically shown that employing multi-level electrical signals can drastically simplify the modulator construction for M-PSK modulation [1]. However, experimental demonstrations have not been shown because of the problem of ISI.

Here we describe a first experimental demonstration of an M-PSK versatile modulation scheme in which we used only a single-electrode straight-line PM. The modulator was driven by a multi-level electrical signal. The ISI caused by the use of a multi-level electrical signal was compensated by pre-equalization based on electronic digital processing.

2. Experimental setup

Figure 2 shows the experimental setup using only a single straight-line PM. In the experiment, we employed self-homodyne detection based on a polarization-multiplexed pilot-carrier [7]. The beam from an external-cavity laser diode (EC-LD) with an emission wavelength of 1551 nm and a linewidth of 200 kHz was modulated by using a single PM which was a simple single-electrode straight-line PM without a polarizer. The modulator modulated mainly the TM polarization component. Therefore, the TE component could be used as a phase reference for the self-homodyne detection [7]. Multi-level electrical signals for the M-PSK modulation, including binary PSK (BPSK), QPSK, and 8-PSK, were applied to the modulator from an arbitrary waveform generator (AWG). The data throughput was set at 10 Gbit/s. The multi-level signal patterns were generated using binary 2^9-1 pseudo-random bit sequence (PRBS) patterns. Pre-equalization (pre-Eq) by electronic digital signal processing with a 16-tap transversal filter was applied to the signals to suppress ISI distortion caused by the use of multi-level signals [1]. At the receiver side, the modulated optical signal was divided into I and Q arms, each including a manual polarization controller, a polarization beam splitter (PBS), and balanced photo-detectors (PDs) with an RF pre-amplifier for the self-homodyne detection [7]. The bit-error-rate (BER) was measured with an error detector (ED), while simultaneously observing the constellation using an oscilloscope.

OMK8.pdf

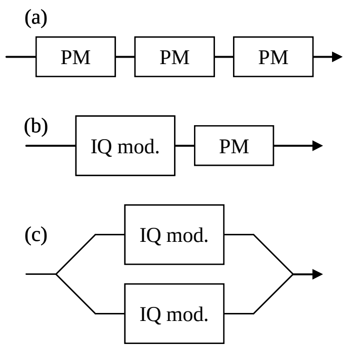

Fig. 1. Conventional implementations of 8-PSK modulation. (a) Three tandem phase modulators, (b) an IQ modulator and a phase modulator, and (c) a quad-parallel MZ modulator.

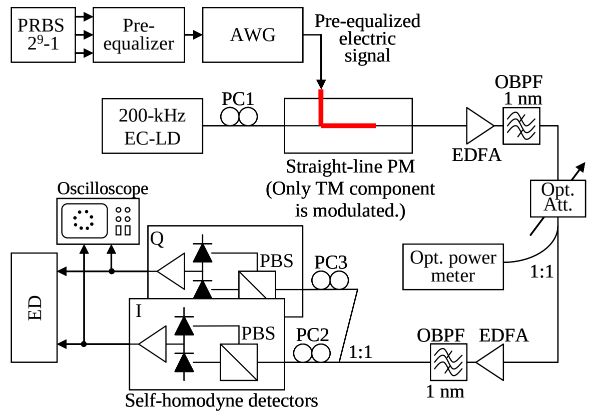

Fig. 2. Experimental setup for 10-Gbit/s M-PSK versatile modulation/demodulation using a single-electrode straight-line phase modulator.

3. Results and discussion

Figure 3(a) shows the observed constellations in the case of BPSK without and with pre-equalization for ISI suppression. In this case, the electrical signal applied to the modulator was not multi-level, and all the electrical components, including the modulator and driver amplifiers, worked in binary mode. Therefore, the ISI caused by the modulation was almost completely suppressed in the same manner as in the scheme of Fig. 1(a). However, we observed that the pre-equalization made the phase points in the constellation smaller. Figure 4(a) shows the observed eye-diagrams of the BPSK signals without and with pre-equalization. A clearer eye opening was observed by applying pre-equalization as shown in the figure. The open and closed circles in Fig. 5 show the BER performance in the case of BPSK without and with the pre-equalization, respectively. The receiver sensitivity was improved by about 2 dB at a BER of 10^{-9}. Figure 3(b) shows the constellations observed in the case of 10-Gbit/s (5-Gsymbol/s) QPSK modulation without and with pre-equalization. In this case, the phase points in the constellation were drastically improved by the equalization. Eye-openings of I- and Q-components were also improved, as shown in Figs. 4(b) and (c). The BER performance in the case of QPSK without and with pre-equalization is denoted by open and closed triangles in Fig. 5, respectively. The receiver sensitivity was improved by about 12 dB at a BER of 10^{-9}. Figure 3(c) shows the constellations in the case of 10-Gbit/s (3.34-Gsymbol/s) 8-PSK without and with pre-equalization. When the pre-equalization was not used, the constellation was completely destroyed by ISI, as shown in the figure, and the BER performance could not be measured. By employing the pre-equalization, however, clear phase points could be observed. Floor-less BER performance of less than 10^{-9} was observed, as denoted by the closed squares in Fig. 5. However, the receiver sensitivity for the 8-PSK signal was about 10 dB lower than that for the BPSK and QPSK signals at a BER of 10^{-9}. This penalty was caused by the comparatively smaller phase-point spacing of the 8-PSK signal and residual ISI which could not be completely compensated by the pre-equalization. However, this problem will be resolved by employing advanced equalization schemes, such as a decision feedback algorithm at receiver side.

4. Conclusions

We experimentally demonstrated M-PSK versatile modulation, including BPSK, QPSK, and 8-PSK, using only a single straight-line PM and digital signal processing for ISI suppression. In the experiment, the equalization was performed at the transmitter side. However, it is also possible to perform the equalization with dispersion compensation by digital signal processing at receiver side. Furthermore, the proposed method can be generally used in other detection schemes, such as digital coherent detection and differential detection.

This work was supported in part by a project of the Ministry of Internal Affairs and Communications of Japan.

5. References

[1] N. Kikuchhi et al., “Multilevel signalling for high-speed optical transmission,” ECOC2006, Tu3.2.1 (2006).
[2] J. Yu et al., “17 Tb/s (161x114 Gb/s) PolMux-RZ-8PSK transmission over 662 km of ultra-low loss fiber using C-band EDFA amplification and digital coherent detection,” ECOC2008, Th.3.E.2 (2008).
[3] J. B. Jensen et al., “Transmission of 32.1 Gbit/s RZ-D8PSK over 160 km using dispersion compensation by optical phase conjugation,” OFC2009, JWA39 (2009).
[4] R. Freund et al., “30 Gbit/s RZ-8-PSK transmission over 2800 km standard single mode fibre without inline dispersion compensation,” OFC2008, OMI5 (2008).

OMK8.pdf

[5] T. Sakamoto et al., "Electro-optic synthesis of 8PSK by quad-parallel Mach-Zehnder modulator," OFC2009, OTuG4 (2009).

[6] N. Kikuchi, "Intersymbol interference (ISI) suppression technique for optical binary and multilevel signal generation," J. Lightwave Technol. **25**, 2060-2068 (2007).

[7] M. Nakamura et al., "Linewidth-tolerant 10-Gbit/s 16-QAM transmission using a pilot-carrier based phase-noise cancelling technique," Opt. Express **16**, 10611-10616 (2008).

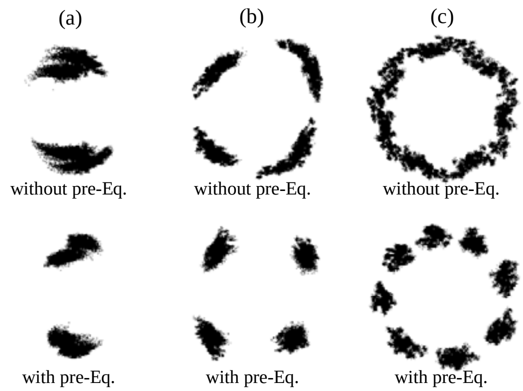

Fig. 3. Constellation diagrams of the received M-PSK signals. (a) BPSK without and with pre-equalization, (b) QPSK without and with pre-equalization, and (c) 8-PSK without and with pre-equalization.

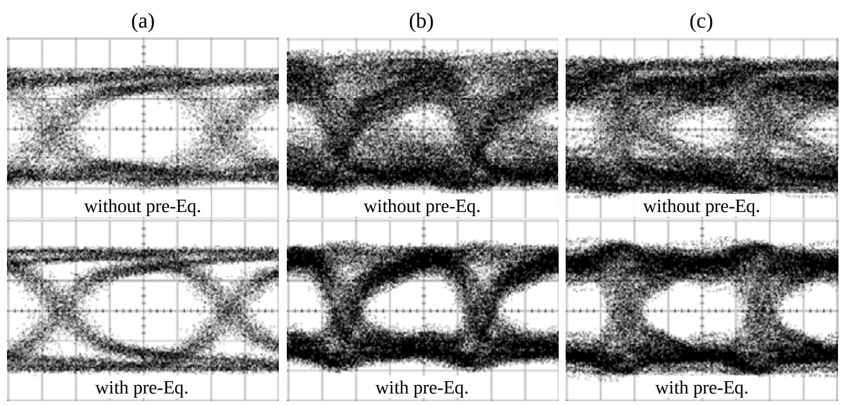

Fig. 4. Eye-diagrams of the received M-PSK signals. (a) BPSK without and with pre-equalization, (b) QPSK (I-component) without and with pre-equalization, and (c) QPSK (Q-component) without and with pre-equalization.

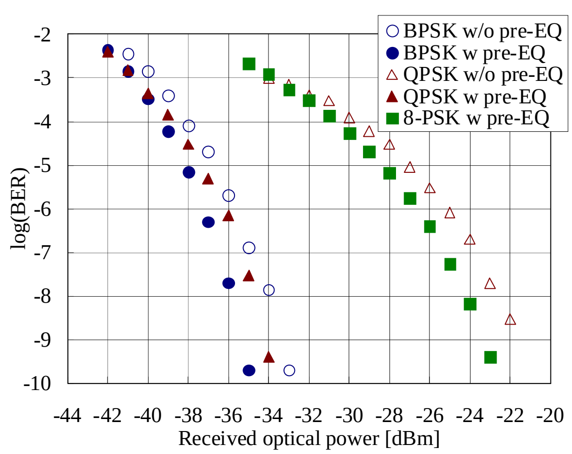

Fig. 5: BER characteristics of the received 10-Gbit/s M-PSK signals with and without pre-equalization based on electronic digital processing.