Coherent Demodulation of 10-Gb/s Optical Minimum-Shift Keying

Takahide Sakamoto, Guo-Wei Lu, Akito Chiba, Tetsuya Kawanishi and Tetsuya Miyazaki
National Institute of Information and Communications Technology, 4-2-1 Nukui-kitamachi, Koganei-shi, Tokyo 184-8795, Japan
tsaka@nict.go.jp

Abstract: We propose and demonstrate a digital coherent detection scheme for demodulation of optical MSK signal. A 10-Gb/s MSK signal synthesized by using a quad Mach-Zehnder in-phase/quadrature modulator was experimentally demodulated by the detection scheme.

OCIS codes: (060.4510) Optical communications; (060.1660) Coherent communications;

1. Introduction

An optical minimum-shift keying (MSK), a representative format of continuous-phase modulation [1-8], exhibits narrower occupied bandwidth comparing with a binary phase-shift keying (BPSK), keeping receiver sensitivity as high as that of BPSK. Optical MSK was, in the earlier days, demonstrated by using direct modulation of laser diode [1][2]. In the last few years, it has been challenging to achieve external modulation in the MSK format aiming for higher bit rate operation [5-8]. Previously, we have demonstrated synthesis of an optical MSK signal with a special IQ modulator called quad Mach-Zehnder (MZ) in-phase/quadrature (IQ) modulator [9], where two carrier-suppressed return-to-zero DPSK (CSRZ-DPSK) signals are orthogonally superposed to optically synthesize the MSK signal [10]. Features of the technology are that 1) the MSK signal synthesized with the modulator can ideally have a constant envelope and the modulator can be, in principle, operated 2) at any wavelength and 3) at any bit rate. On the other hand, techniques of coherent detection, especially in a digital manner, have been rapidly progressed, showing great promises [11][12]. It has been proved that such coherent detections can be effectively applicable to several useful advanced modulation formats like QPSK, QAM, and so on [11][12]. In this paper, we propose and investigate coherent demodulation of optical MSK based on digital homodyne method. Benefits of the coherent detection of MSK are that 1) good receiver sensitivity as like a coherent demodulation of PSK signals, 2) narrower analogue bandwidth is required in the receiver side comparing with BPSK at the same bit rate. To our best knowledge, there was no report focusing on coherent demodulation of MSK signal in a digital way. Actually, in our former demonstration, the synthesized MSK signal was demodulated by a delay interferometer for frequency discrimination. In this paper, a 10-Gb/s MSK was experimentally demodulated by the proposed MSK coherent receiver.

2. Principles

2.1. Transmitter for optical MSK based on a quad-MZ IQ modulator

Fig. 1 shows how an optical MSK signal is synthesized by using a quad-MZ IQ modulator. The quad-MZ IQ modulator consists of four MZMs and it has a special structure, where two cascaded modulators are integrated in each arm of the main MZM. Each MZM is driven in the following way. By driving the first sub-MZM in each arm, MZM 1 or MZM 3, feeding RF clock at frequency, f, and data-modulating the phase difference of the input light using the followed sub-MZM (MZM 2/MZM 4) a CSRZ-DPSK is generated in each arm. To achieve continuous-phase modulation in MSK format, f should be set at half of the bit rate, B; the two CSRZ-DPSK streams should be off-set with a half-bit delay; and the relative optical phase difference should be $\pi/2$. In this way, the USB or LSB could be alternatively generated according to the sign of the relative phase difference between the two CSRZ-DPSK streams. This operation can effectively make the modulation spectrum compact and suppress undesired sideband components comparing to DPSK.

2.2. Coherent receiver for optical MSK

Here, we describe coherent demodulation of optical MSK. For demodulation of MSK in a coherent manner, heterodyne or homodyne detection can be applicable. In this report we take the approach of homodyne detection because the scheme could outperform in terms of demodulation of high-speed signals. The receiver setup for homodyne detection for optical MSK is almost same as the commonly used one for detection of PSK. The received MSK signal is projected onto optical phasor space of the local oscillator. On the phasor space, USB/LSB components corresponding to mark/space (or space/mark) state of the MSK signal circularly rotates in the clockwise/counter-clockwise direction; the amount of phase shift in each bit duration is $\pi/2$. If the received signal is sampled at the timing of middle point of each bit with the sampling rate of B b/s, four symbols with equal spacing on the circle would appear on the IQ map like a constellation of QPSK, and its original data is recovered from the I and Q components by giving thresholds to them. This detection scheme is easily implemented to so-called digital homodyne receiver only with some minor changes to the QPSK receiver.

3. Experiments

Fig. 2 shows experimental setup for coherent modulation and demodulation of optical MSK at 10 Gb/s. In a transmitter side, a CW light with a line width of 150 kHz was generated from an external cavity laser diode; the CW light was externally modulated in the MSK format by using the quad-MZ IQ modulator. The modulator was based on Z-cut LN waveguide modulator and 3-dB bandwidth of the modulation electrode was about 36 GHz. The half wave voltage of each MZM was 6.0 V at DC frequency. Each MZM was biased at the null point and push-pull driven with a pair of differential signals. MZM 1 and MZM 3 were driven with a pair of sinusoidal clocks at the frequency of 2.5 GHz. The phase difference between the clocks was set at 90 degree. MZM 2 and MZM 4 were driven with two streams of 5-Gb/s NRZ data in a pseudo-random bit sequence with the length of 2^{15}-1; 100-ps delay was given between the data streams. Under the operating conditions, 5-Gb/s CSRZ-BPSK signal was generated in each arm of the main MZM; by giving 90-degree phase offset between them, the two signals are orthogonally superposed to form a 10-Gb/s MSK signal.

In a receiver side, the MSK signal was received with an offline digital coherent receiver designed for the MSK format. The I and Q components of the received signal projected to an LO light was detected with a 90-degree hybrid coupler followed by two pairs of balanced detectors. The LO light was generated from another external cavity laser diode and frequency detuning between the LO and signal was tuned within less than ~500 MHz. The I and Q components were recorded with a real-time sampling oscilloscope with a sampling rate of 50 Gsa/s. In the offline signal processing, the recorded data were re-sampled at the sampling rate of 10 Gsa/s and carrier-phase was estimated using so-called fourth-power algorithm. Once after the sampling at the optimal points, the sampled signal can be treated in a similar way as the demodulation of QPSK. An adaptive FIR filter with the tap length of 15 was applied for equalization.

Fig. 3 (a) shows a constellation map of the received MSK signal sampled at the optimum timing, i.e. the middle point of each bit duration. Note that four symbols appeared on the constellation map like a QPSK signal, as we had expected, which is a proof of demodulation of MSK. As shown in Fig. 3(b), the modulation spectrum had the bandwidth of 15 GHz, which is another proof that the signal received is in the MSK format. Fig. 3(c) shows back-to-back bit-error-rate (BER) characteristics of the received MSK. The receiver sensitivity for error free operation (BER < 2×10^{-6}) was -36.3 dBm.

4. Summary

In this paper, we investigated coherent demodulation of optical MSK. A 10-Gb/s optical MSK signal generated from a quad-MZ IQ modulator was successfully demodulated by a newly proposed demodulation scheme based on digital homodyne method.

References

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References

[1] K. Iwashita and T. Matsumoto, J. Lightwave. Technol., LT-5 (1987) pp. 854-856
[2] B. Wedding et al., ECOC’03., Th1.5.5 (2003).

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[3] T. Sakamoto et al., OFC'05., OFG2 (2005).
[4] Y. Miyamato et al., OFC'05., OTuL2 (2005)
[5] T. Sakamoto, et al, ECOC'05., Th.2.2.5 (2005),
[6] J. Mo et al., ECOC'05., Th.1.2.3 (2005)
[7] T. Sakamoto, et al, OFC'05.,
[8] M. Rohde, et al, ECOC'08., Mo.4.E.4 (2008).
[9] G.W. Lu et al., ECOC'08., PDP Th.3.D.5 (2008).
[10] G.W. Lu et al., ECOC'09., 5.2.1 (2009).
[11] S. Tsukamoto et al, OFC'05., PDP29 (2005).
[12] H. Sun *et al*, Opt. Express 16, pp. 873-879 (2008).

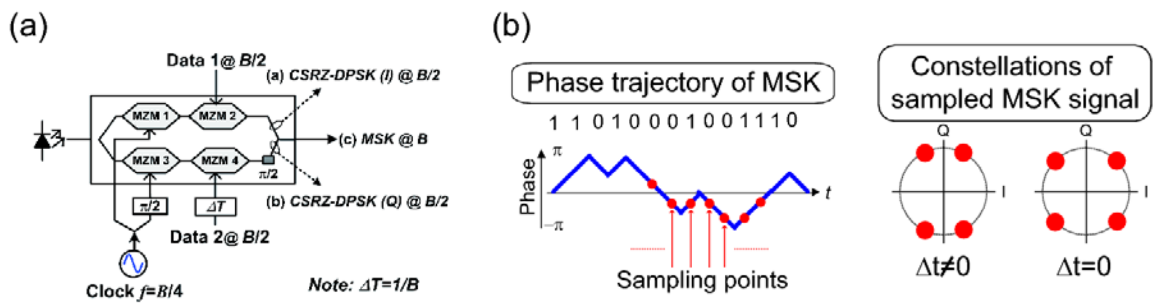

Fig. 1. (a) quad-MZ IQ modulator for synthesis of MSK signal, (b) principle of demodulation of optical MSK by digital homodyne

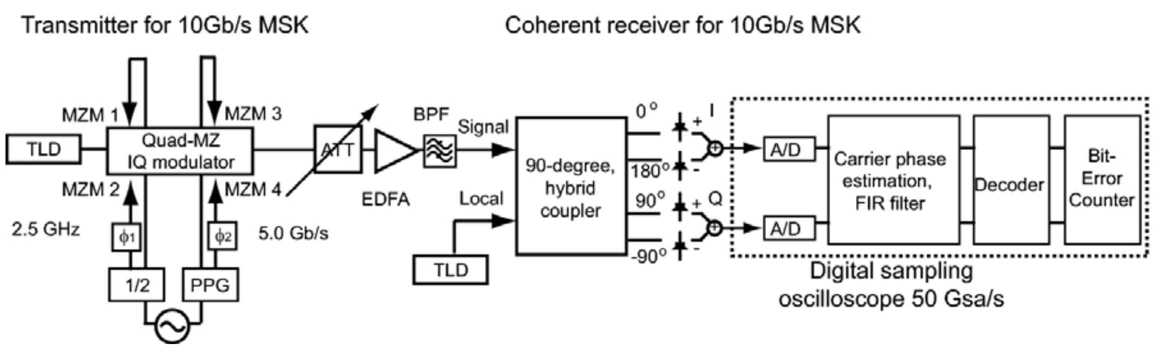

Fig. 2. Experimental setup

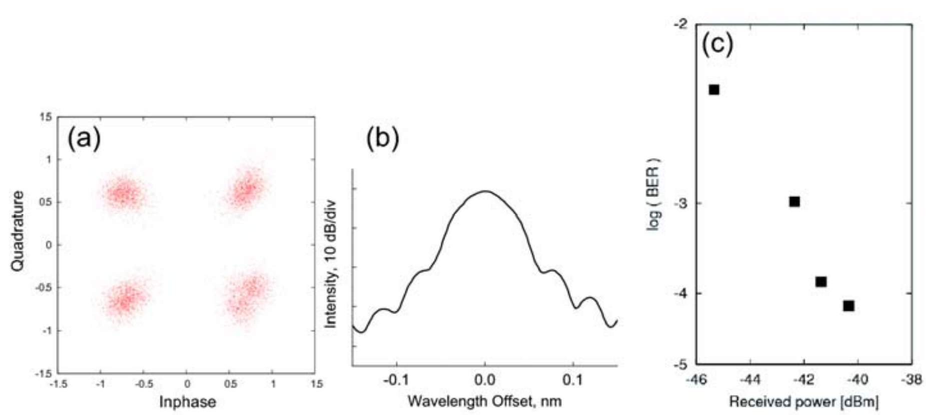

Fig. 3. Experimental results: (a) a constellation map measured with the received power of -36.3 dBm, (b) optical spectrum, (c) BER characteristics