Generation of 16-Gb/s MSK signal using a single 10-GHz SSB modulator and simplified encoder/decoder

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Abstract: We propose a new scheme for generating optical MSK by using a commercial SSB modulator. The demodulation of the signal is based on a 2-bit delay MZI to simplify pre-coding/decoding circuits. This scheme is successfully demonstrated in a 16-Gb/s system.
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1. Introduction

Novel optical modulation formats have been introduced into optical communications to provide advantageous features such as increased spectrum efficiency, enhanced tolerance to fiber dispersion and nonlinearity, and improved optical signal-to-noise ratio performance. These new formats include differential phase shift keying (DPSK), continuous phase frequency shift keying (CPFSK), and so on. Minimum shift keying (MSK) is a special case of CPFSK with a modulation index h = 0.5, which is a well-known modulation format in wireless communications. In optical communications, MSK was investigated in coherence optical systems. Recently optical MSK has received much attention due to its constant amplitude and narrower power spectrum. These features make it greatly attractive for long-haul transmissions; as the compact spectrum and the constant amplitude provide potentially good dispersion and nonlinearity tolerance. In previous works, MSK signal was generated by a directly modulated DFB laser with a frequency swing of half bit rate [1], however the modulation bandwidth is limited by the response of the laser, and the accompanying AM noise is not negligible. Recently, some attractive MSK generation schemes were proposed using specially designed modulators, such as frequency shift key (FSK) modulator, which is a modified single side band (SSB) modulator with a high-speed RF port for data modulation [2], or a dual-parallel modulator with a customer-designed 1-bit delay line integrated between the two arms [3]. In both cases, there is significantly added cost associated with the special modulators. In addition, the schemes based on 1-bit differential demodulation require complex data encoding and decoding for the In-phase (I) and the Quadrature (Q) tributaries.

In this paper, we propose a novel MSK generation scheme by using a commercially available optical SSB modulator with a 10-GHz bandwidth to generate 16-Gb/s MSK signal, which is the highest rate reported to date, to the best of our knowledge. The demodulation is based on a 2-bit delay MZI, which is shown to simplify encoding/decoding circuits.

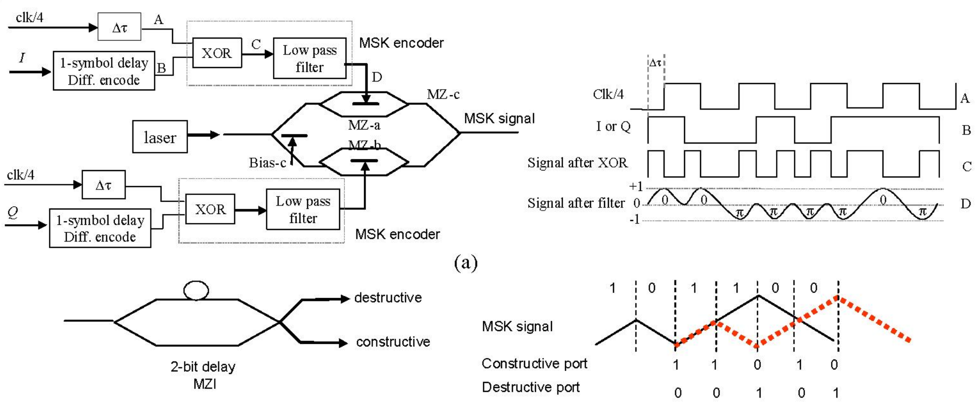
2. Principles

Fig.1(a) shows the proposed MSK transmitter configuration using an SSB modulator. The SSB modulator consists of a pair of Mach-Zehnder modulators (MZ-a, MZ-b) embedded in two arms of a primary MZ structure (MZ-c). MZ-a and MZ-b are used for generating I and Q components of the MKS signal, respectively. The I signal is first differentially encoded at the symbol rate (half of the bit rate B), and then sent to an XOR gate with a B/4-clock with a certain delay. The output signal of the XOR-gate is filtered by a low pass filter having a 3dB bandwidth of ~75% of the symbol rate. As a result, a sinusoidal weighted bipolar signal is obtained. The bipolar signal is applied to the MZ-a biased at its null position, to modulate a continuous-wave (CW) light and generate the I component of the MSK signal, which is actually a CSRZ-DPSK signal. The Q component is encoded using the same method and applied to MZ-b, with a 1-bit delay. When the optical phase difference between the two arms of MZ-c controlled by bias-c is $\pi/2$, the MSK signal is obtained at the output of SSB modulator.

From the coding point of view, MSK modulation equivalently implements a 1-bit delay-correlation to the serial data stream; therefore a 1-bit delay differential pre-coding of original serial data must be employed to enable correct recovery of the original data sequence in the receiver. It should be emphasized that the 1-bit delay MZI with the $\pi/2$ optical phase difference between the two arms in conventional schemes is only used as an optical filter, but not for decoding. In practice, however, the I and Q components come from different users. The differential pre-coding of a serial data means that the two signals have to be multiplexed by a serializer, after which differential encoding to this serial data stream is applied, and finally the serial data needs to be de-multiplexed to the *I* and *Q* components again by a deserializer. This approach has added complexity and is difficulty to implement at high-speed data rate. In our proposal, the differential pre-coding with 1-symbol delay (or 2-bit delay) is applied directly onto the *I* and *Q* data, respectively. It is equivalent to implementing the differential encoding to a serial data with a 2-bit delay, therefore in addition to the 1-bit correlative decoding through MSK modulation in the transmitter, another 1-bit correlative decoding should be performed at the receiver. Fig.1b shows the principle for realizing the 1-bit delay correlative decoding using a 2-bit delay MZI. Owning to the phase trajectory property of the MKS signal, an output bit s_i from the MZI is determined by 2 previously bits of the input, which is given by:

$$s_i = x_{i-1} \oplus x_{i-2} \quad \text{at constructive port} \qquad s_i = \overline{x_{i-1} \oplus x_{i-2}} \quad \text{at destructive port}$$

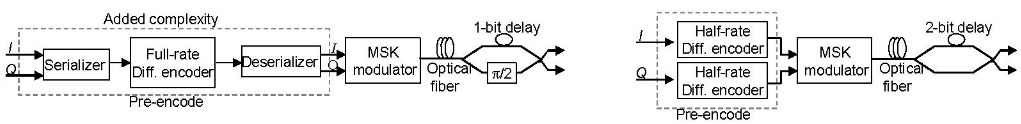
where x_i is the input bit of the MSK signal. Clearly the MZI implements 1-bit correlative decoding to the input MSK signal. For comparison, the proposed and conventional method of MSK transmitter and demodulation is also shown in figure 2.



(a)

(b)

Fig. 1. Principle of the proposed (a) MSK transmitter using an SSB modulator and (b) correlative decodingn using a 2-bit delay MZI



(a) (b)

Fig. 2. (a) Conventional MSK transmitter and demodulation showing added complexity, (b) proposed MSK transmitter and demodulation

3. Experiment and results

The experiment setup used to demonstrate the scheme is shown in Fig.3. The transmitter consists of a DFB laser, a $LiNbO_3$ SSB modulator and a MSK encoder. The MSK encoder includes a high speed XOR-gate and a low pass filter, with a 3-dB bandwidth of ~6GHz. The SSB modulator has a 3dB bandwidth of about 10GHz. An 8-Gb/s pseudo-random binary sequence (PRBS) data of 2^7-1 length, and a 4-GHz clock, are the inputs to the MSK encoder to generate the sinusoidal weighted bipolar drive signal. The delay between the clock and data is optimized by monitoring the eye diagram of the bipolar signals. The signal is then divided into two paths as *I* and *Q* components. One signal is delayed by a 0.5m cable for de-correlation purpose. MZ-a and MZ-b are driven by the bipolar signals, respectively, with an amplitude of ~7V. The output of the SSB modulator is a 16-Gb/s MSK signal. After amplified by an EDFA, MSK signal is sent into a 2-bit delay MZI for demodulation, which is then separated to *I* and *Q* bit sequences by a $LiNbO_3$ MZ modulator driven with an 8-GHz synchronous clock. The *I* and *Q* components are detected by a single-ended optical receiver respectively.

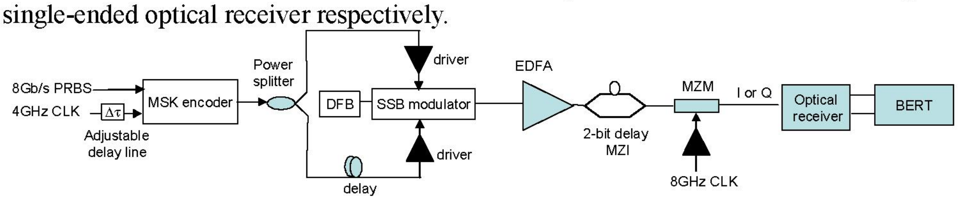


Fig. 3. Experiment setup

The eye diagram of the sinusoidal weighted bipolar drive signal is shown in Fig.4(a). Some amplitude noise and timing jitter on the eye diagram can be attributed to the non-ideal impedance match in the printed circuit board of MSK encoder. Fig. 4(b) shows the eye diagram and the optical spectrum of the MSK signal. It can be seen that the optical spectrum of the MSK signal is narrow and the amplitude is almost constant. However the amplitude fluctuation of the de-modulated signal at the constructive port is obvious, as shown in Fig.4(c). The main reasons are the distortion of the bipolar drive signal induced by non-ideal impedance match, and the difference in the extinction ratio between MZ-a and MZ-b. The spectrum of demodulated MSK signal using 2-bit delay MZI is different from the one using a 1-bit delay MZI with the $\pi/2$ optical phase difference between the two arms in conventional scheme, but similar to the de-modulated DPSK signal, as shown in Fig.4(c) and Fig.4(d). That means the correlative decoding using 2-bit delay MZI is successfully achieved.

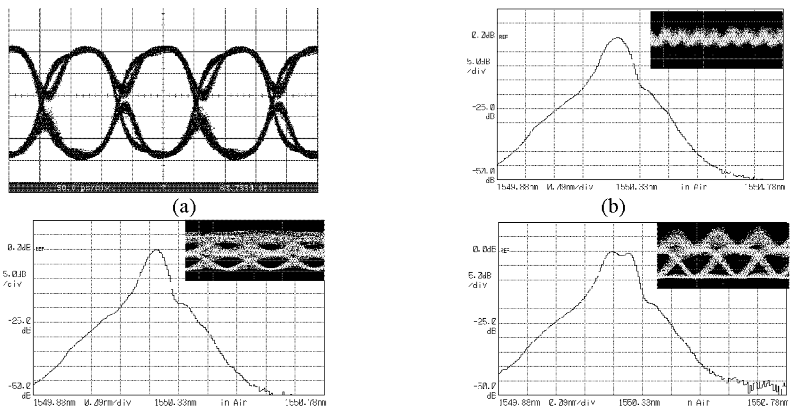


Fig. 4. (a) eye diagram of the sinusoidal weighted bipolar drive signal, (b) eye diagram and optical spectrum of the MSK signal, (c) de-modulated signal at the constructive port, (d) de-modulated signal at the destructive port

Fig.5 shows the measured BER performance of the *I* and *Q* components. Error-free operations are achieved using the single-ended optical receiver, and the receiver sensitivity (BER=10^{-10}) for *I* and *Q* signal are -20.0dBm and -19.2dBm respectively.

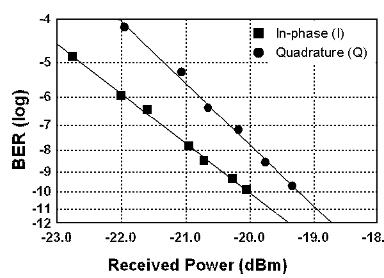


Fig. 5 Measured BERs of the *I* and *Q* components

4. Conclusions

We proposed a new high-speed optical MSK signal generation scheme, and demonstrated 16-Gb/s MSK signal by using a commercial 10-Gb/s optical SSB modulator and its demodulation based on a 2-bit delay Mach-Zehnder interferometer to simplify the encoding and decoding circuits.

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