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Novel FSK format for 40-Gb/s transmission using FSK modulator

Liu Yang, Fengguang Luo *

National Engineering Laboratory for Next Generation Internet Access System, School of Optical and Electronic Information, Huazhong University of Science and Technology, 430074 Wuhan, China

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ABSTRACT

We propose and investigate a novel frequency shift keying (FSK) format for 40-Gb/s transmission system. In this paper, we present the generation, the dispersion compensation, the detection and the performance evaluation of the proposed FSK format. FSK signal is generated based on the bias voltages of a novel external FSK modulator, which is consisting of two $LiNbO_3$ Mach–Zehnder (MZ) modulators. By numerical simulation, the transmission performance and the different dispersion compensation schemes of the FSK signal are discussed.

1. Instructions

In the past few years, a lot of advanced modulation formats have been proposed and investigated to enhance the performance of the high-speed optical transmission system [1–3]. In the different modulation format, frequency shift keying (FSK) modulation format enables differential detection scheme, and simulations have shown that it has a comparable gain of optical signal noise rate sensitivity (OSNR) to different phase shift keying (DPSK) in a 10-Gb/s transmission system [4]. Furthermore, the orthogonal modulation, the combination of the amplitude shift keying (ASK) and FSK has attracted much attention for its high-spectral, simple detection, and good performance in high-speed transmission system [5–7]. Therefore, FSK is one of the potential solution for the future optical transmission system and the optical packet switching network. In previous works, FSK signals are directly generated by modulating the electric current of the laser. However, because of the current jitter, a parasitic intensity modulation should be compensated by an additional intensity modulator [7,8]. The FSK signals can be generated by a MZ modulator, two lasers and the Mach–Zehnder delay interferometer (MZDI) using the technology of the demodulation of the differential phase shift keying (DPSK). This method with complex construction is deeply influenced by the jitter of the laser's frequency [9,10]. An external FSK modulator, which is consisting of six phase modulators, is driven by two sinusoidal signal and data signal to generate FSK format. The frequency of the sinusoidal signal limits the transmission performance and the transmission speed of the FSK format [11,12].

In this paper, we propose a novel scheme for generation of FSK signal that can reach bit rate at 40-Gb/s and above. FSK signal is generated by a novel FSK modulator, which is consisting of two $LiNbO_3$ MZ modulators (four phase modulators). The FSK modulator is directly driven by the data without the sinusoidal signal. In addition, the transmission performance and the different dispersion compensation of this scheme is discussed in this paper.

2. FSK modulator

The structure of the FSK modulator is shown in Fig. 1. The FSK modulator consists of two $LiNbO_3$ MZ modulators. A $LiNbO_3$ MZ modulator is analyzed, firstly. The output of the $LiNbO_3$ MZ modulators can be expressed by

$$E_o = \frac{E_{in}}{2}\left(1 + e^{\frac{j\pi V(t)}{V_\pi}}\right) = E_{in}\cos\left(\frac{\pi V(t)}{2V_\pi}\right)e^{\frac{j\pi V(t)}{V_\pi}} \tag{1}$$

$$V(t) = V_{RF}(t) + V_B(t) \tag{2}$$

Where, E_{in} is the electric field of the input light wave; E_o is the electric field of the output light wave; $V(t)$ is the driven modulating voltage, which contains the radio frequency (RF) driven voltage $V_{RF}(t)$ and the direct current (DC) driven voltage $V_B(t)$; the DC driven voltage $V_B(t)$ and the RF driven voltage $V_{RF}(t)$ can be controlled by the RF electrode; and V_π is the switch voltage. The power transmission curve of the MZ modulator is shown in Fig. 2. In the FSK generation, the output optical signal is inverted or identical with the RF signal in accordance with different bias

* Corresponding author.
E-mail address: fgluo@hust.edu.cn (F. Luo).

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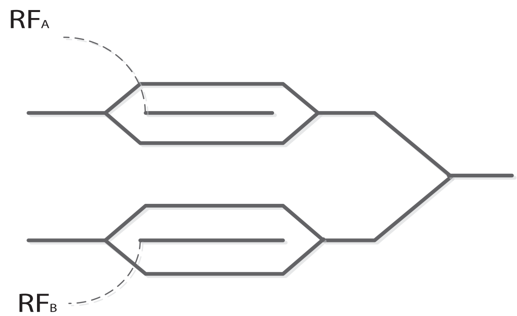

Fig. 1. FSK modulator.

voltages. When the RF signal $V_{RF}(t)$ is equal to V_π, the DC voltage $V_B(t)$ with 0 V can make the output optical signal logically inverted to the RF signal; however, DC voltage $V_B(t)$ with V_π can make the output electric field signal the same to the RF signal. The output signals in the two cases are logically inverted in uniform amplitudes. In this modulator, the RF signal is the data signal.

When the voltages (0 and V_π) of $V_B(t)$ are applied to the electrodes (RF_A and RF_B) of the two $LiNbO_3$ MZ modulators respectively, the two output signals of the $LiNbO_3$ MZ modulators are logically inverted in uniform amplitudes. When the two optical signals are combined by the Y-branch of the FSK modulator, the FSK signal is generated. The modulation principle of the FSK signal can be shown in Fig. 2.

3. Numerical simulation and results

The transmission performance and the different dispersion compensation of the FSK signal is evaluated through numerical simulations using commercial software. The structure of the FSK transmission system is shown in Fig. 3. At the transmitter, two continuous wave (CW) lasers are selected with certain frequencies (193.1 and 193.2 THz) and utilized as the transmitter's source. The half-wave voltage (V_π) of the FSK modulator is 4 V. Therefore, the bias voltage of RF_A and RF_B are 0 and 4 V, respectively. The data stream from the 40-Gb/s pattern generator, with 4 V voltage is pre-coded to driven the electrodes of RF_A and RF_B. Thus, the optical signal from RF_A is logically opposed to the data signal, while the optical signal from RF_B is same to the data signal. Therefore, a

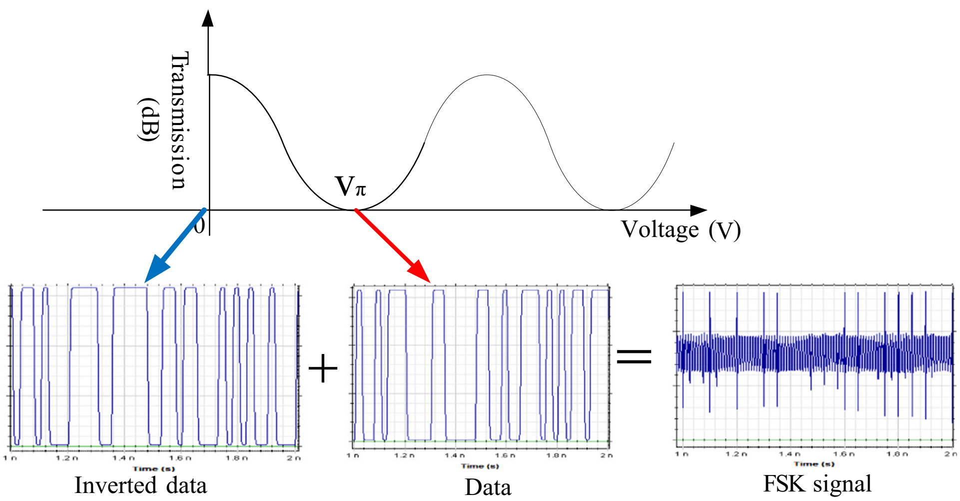

Fig. 2. Principle of the FSK generation.

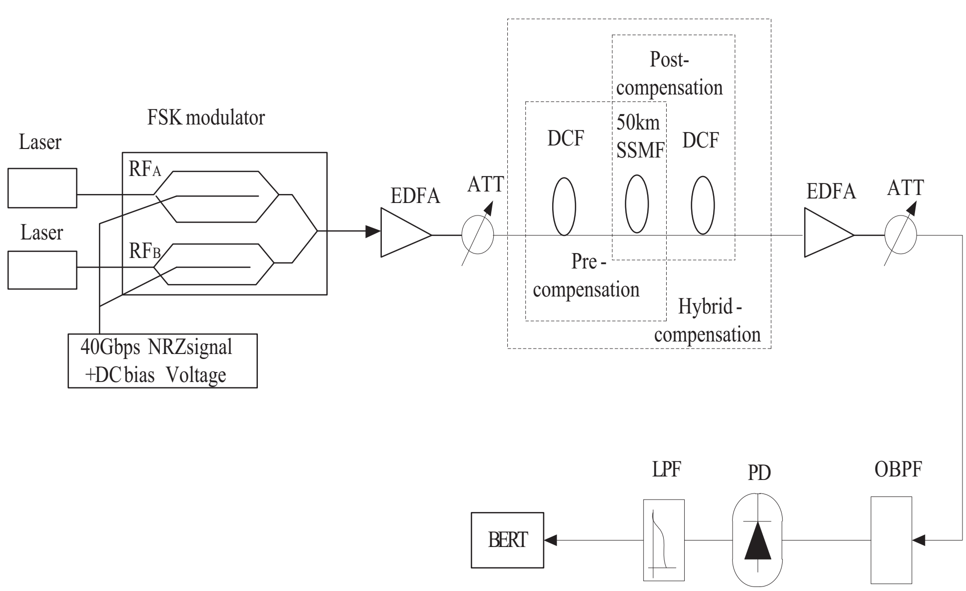

Fig. 3. Structure of the FSK transmission system (DC: direct current, NRZ: not to zero, EDFA: erbium doped fiber amplifier, ATT: attenuator, DCF: dispersion compensation fiber, SSMF: standard single mode fiber, OBPF: optical band-pass filter, PD: photodiode, LPF: low pass filter, and BERT: bit-error ratio tester).