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10 Gbit/s FSK transmission over 95 km SMF using a $LiNbO_3$ modulator

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Abstract: We demonstrate high-speed optical frequency-shift-keying (FSK) transmission over a 95 km single-mode fiber (SMF) at 10 Gbit/s using a $LiNbO_3$ optical FSK modulator and an optical interleaver. The measured eye diagrams, bit error rate (BER) performances and optical spectrum indicate the FSK modulation is similar to zero chirp non-return-to-zero (NRZ) on-off-keying (OOK) transmission. Therefore, in view of dispersion tolerance, the FSK modulation can be treated as well as NRZ OOK.

Keywords: frequency-shift-keying, $LiNbO_3$ modulator, zero chirp

Classification: Photonics devices, circuits, and systems

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1 Introduction

Frequency-shift-keying (FSK) modulation for coherent optical systems was investigated to obtain enhanced receiver sensitivity, in previous works [1]. Recently, optical packet systems using FSK technique have received considerable attention. FSK is an effective scheme for optical labeling, where payload signals are transmitted by conventional intensity modulation and direct detection [2]. The label information can be extracted without affecting the payload signal. In previous works, FSK signal was generated by direct modulation of electric current in a laser light source [2, 3]. Thus, FSK bit rate was limited by the response of the laser [3, 4]. Recently, however, we reported high-speed optical frequency switching by using an optical FSK modulator consisting of a pair of Mach-Zehnder structures [5, 6], which is based on optical single sideband (SSB) modulation technique [7]. In this paper, we demonstrate optical FSK transmission over a 95 km single-mode fiber (SMF) at 10 Gbit/s using a $LiNbO_3$ optical FSK modulator, where the FSK signal was demodulated by an optical interleaver. And we compare transmission characteristics between FSK and non-return-to-zero (NRZ) on-off-keying (OOK).

2 FSK modulator

The FSK modulator consists of a pair of Mach-Zehnder structures as shown in Fig. 1. The device structure is almost the same in the SSB modulator [7], but the FSK modulator has an electrode RF_C for high-speed FSK signal, instead of a dc-bias electrode in the SSB modulator. When we apply a pair of rf-signals, which are of the same frequency (f_m) and have 90° phase difference, to the electrodes RF_A and RF_B, frequency shifted lightwave can be generated at the output port of the modulator. A sub Mach-Zehnder structure of path 1 and 3 should be in null-bias point (lightwave signals in the paths have 180° phase difference), where the dc-bias can be controlled by RF_A. The other sub Mach-Zehnder structure of path 2 and 4 are also set to be in null-bias point by using RF_B. To eliminate upper sideband (USB) or lower sideband (LSB), the lightwave signal in each path also should have 90° phase difference each other. When the phase difference induced by RF_C is 90°, we can get carrier-suppressed single sideband modulation comprising one of the sideband components (USB or LSB). The amplitudes of USB and LSB are, respectively, described by $[1 + i\exp(i\phi_{\mathrm{FSK}})]/2$ and $[1 + i\exp(-i\phi_{\mathrm{FSK}})]/2$, where ϕ_{FSK} is the induced phase difference at RF_C, and $\phi_{\mathrm{FSK}} = 90°$ corresponds to an optimal condition for USB generation. Thus, by feeding an NRZ signal, whose zero and mark levels respectively correspond

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to $\phi_{FSK} = +90°$ and $-90°$, to RF_C, we can generate an optical FSK signal, without any parasitic intensity modulation. In the SSB modulator previously reported, the electrode for optical phase control was not designed for high-speed operation, so that the switching time was limited by the response of the electrode. On the other hand, the FSK modulator has the electrode RF_C for high-speed optical phase switch at the junction of a pair of sub Mach-Zehnder structures.

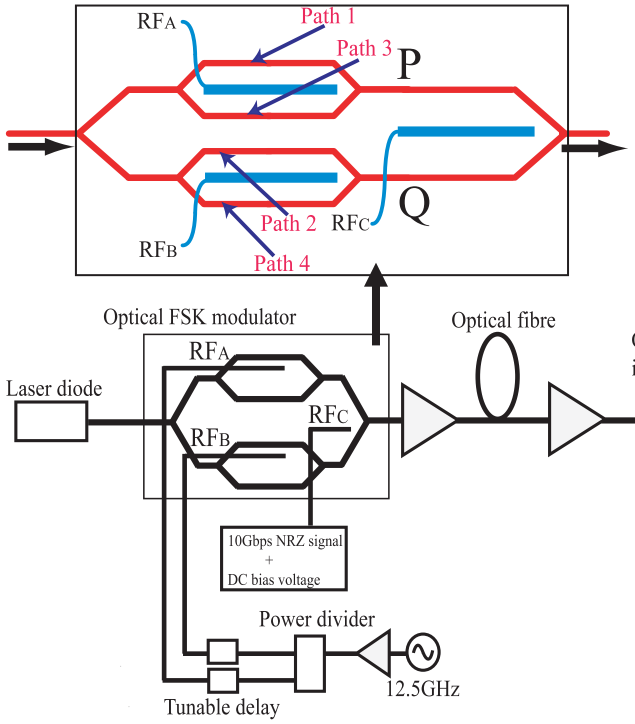

Fig. 1. Setup and device structure of optical FSK modulator.

3 FSK transmission

Fig. 1 shows an experimental setup for optical FSK transmission. In order to obtain high-speed response, we fabricated an optical FSK modulator having an x-cut $LiNbO_3$ lightwave circuit with traveling wave electrodes whose 3 dB bandwidths were 18 GHz. A pair of sinusoidal electric signals having 90° phase difference was applied to the electrodes RF_A and RF_B, for generation of sideband components. The phase difference was controlled by using tunable delay lines. The signal frequency f_m was 12.5 GHz, so that optical FSK deviation was 25 GHz. The optical FSK signal was transmitted via an SMF, and demodulated into an NRZ OOK signal, by an optical spectral interleaver. One of the sideband components (USB or LSB) can be taken out from an optical output port of the interleaver whose channel separation was 25 GHz. The demodulated signal should be similar to a NRZ OOK signal generated by a zero chirp optical intensity modulator (see Fig. 2), because the sub Mach-Zehnder structures in the FSK modulator had balanced electrodes of

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coplanar waveguide, and were constructed on an x-cut $LiNbO_3$ substrate.

We measured bit error rate (BER) performance of FSK transmission. A 9.95 Gbps (NRZ $2^{31}-1$ PRBS) signal was applied to RF_C of the modulator. Fig. 3 (a) shows BER curves of 9.95 Gbps FSK for back-to-back, and after transmission through a 95 km SMF. The results show that the eyes were clearly open and that error-free transmission of 10 Gbps FSK 95 km SMF is possible. Fig. 3 (b) shows power penalties as functions of transmission distance. Power penalty of 95 km transmission with reference to back-to-back at BER $= 10^{-12}$ was 1.7 dB. The slope was similar to that of NRZ OOK. Therefore, in view of dispersion tolerance, the FSK modulation can be treated as well as NRZ OOK.

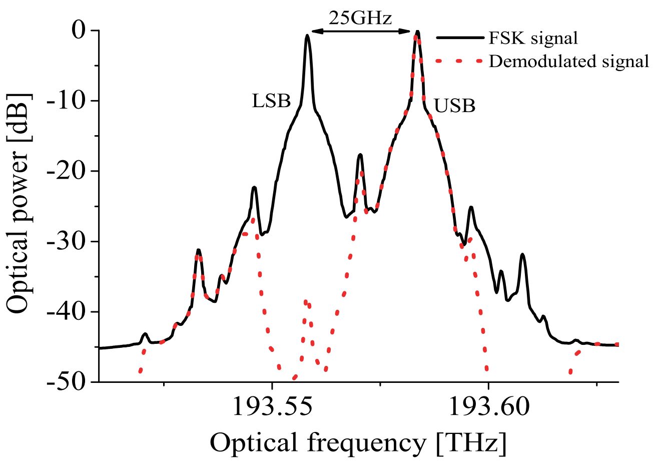

Fig. 2. Optical spectra of FSK signal (solid line) and demodulated signal (dotted line).

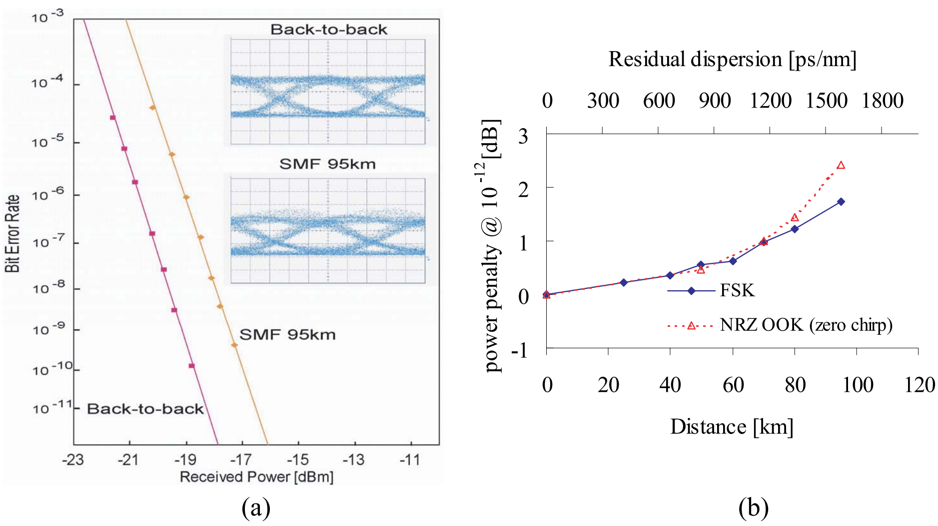

Fig. 3. BER curves and power penalties versus distance.

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4 Conclusion

We demonstrated high-speed optical FSK transmission over a 95 km SMF at 10 Gbit/s using a $LiNbO_3$ optical FSK modulator and an optical interleaver. And its dispersion tolerance was similar to that of NRZ OOK. By using this technique, we can obtain high FSK bit rate with a simple setup, so that the number of the labels can be increased in OOK/FSK optical packet systems.

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