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Optical FSK transmission with group delay compensated balance detection

Tetsuya Kawanishi[1a)], Takahisa Fujita[2], Kaoru Higuma[2], Junichiro Ichikawa[2], Takahide Sakamoto[1], and Masayuki Izutsu[1]

[1] *National Institute of Information and Communications Technology, 4–2–1 Nukui-Kitamachi, Koganei, Tokyo 184–8795, Japan*

[2] *New Technology Research Laboratories, Sumitomo Osaka Cement, 585 Toyotomi, Funabashi, Chiba 274–8801, Japan*

a) *kawanish@nict.go.jp*

Abstract: A novel balance detection scheme for high-speed optical frequency-shift-keying (FSK) transmission was proposed. Fiber dispersion can be compensated by a balanced photodetector with an optical delay. 10 Gbit/s optical FSK transmission over a 130 km single mode fiber was demonstrated, where the FSK signal was generated by using a $LiNbO_3$ high-speed optical FSK modulator.

Keywords: optical modulation, frequency shift keying, balanced detection, group delay

Classification: Photonics devices, circuits, and systems

References

[1] J. J. Vegas Olmos, I. Tafur Monroy, and A. M. J. Koon, "High bit-rate combined FSK/IM modulated optical signal generation by using GCSR tunable laser sources," *Opt. Express*, vol. 11, pp. 3136–3140, 2003.

[2] W. Idler, A. Klekamp, R. Dischler, and B. Wedding, *2004 IEEE/LEOS Workshop on Advanced Modulation Formats*, FD3, 2004.

[3] T. Kawanishi, T. Sakamoto, S. Shinada, M. Izutsu, K. Higuma, T. Fujita, and J. Ichikawa, "High-speed optical FSK modulator for optical packet labeling," *OFC 2004*, PDP16, 2004.

[4] T. Kawanishi, K. Higuma, T. Fujita, J. Ichikawa, T. Sakamoto, S. Shinada, and M. Izutsu, "LiNbO3 high-speed optical FSK modulator," *Electron. Lett.*, vol. 40, pp. 691–692, 2004.

[5] K. Higuma, S. Oikawa, Y. Hashimoto, H. Nagata, and M. Izutsu, "Xcut lithium niobate optical single-sideband modulator," *Electron. Lett.*, vol. 37, pp. 515–516, 2001.

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1 Introduction

Optical frequency-shift-keying (FSK) is an effective scheme for optical labeling, where payload signals are transmitted by conventional intensity modu-

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lation and direct detection. 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 grating-coupler sampled-reflector (GCSR) laser, where FSK bit rate was limited upto a few hundreds of MHz by the response of the laser [1]. On the other hand, we can also obtain high-speed FSK transmission by direct modulation of a distributed feedback laser whose frequency modulation (FM) bandwidth is larger than 10 GHz, but the laser does not respond to signals whose frequency is lower than 10 MHz due to transition between thermal FM and carrier FM [2]. However, recently, we reported high-speed FSK transmission by using an external $LiNbO_3$ optical FSK modulator consisting of a pair of Mach-Zehnder structures, which is based on optical single sideband (SSB) modulation technique [3, 4]. The FSK modulator can respond to broadband signals from dc to 18 GHz. In addition, the input of the FSK modulator can be an intensity modulated signal, so that we can swap the order of the orthogonal modulation formats, while the FSK signal in conventional techniques should be generated prior to intensity modulation for payload signals [1]. By using the external FSK modulator, we can easily construct a simple label swapping system, where restored intensity modulated signals would be fed to the FSK modulator [3].

When the frequency deviation is larger than the signal bandwidth, the FSK signal can be easily converted into an on-off-keying (OOK) signal by using an optical filter. However, the occupant bandwidth of the FSK signal is more than twice compared to the conventional OOK formats. Thus, the demodulated FSK signal would be largely degraded by the fiber dispersion in the occupant bandwidth. In this paper, we demonstrate 10 Gbit/s optical FSK transmission over a 130 km single-mode fiber (SMF), by using a balanced demodulator comprising an optical interleaver, an optical delay and a balanced photodetector. This balance demodulation scheme can enhance the receiver sensitivity. The interleaver discriminated the upper and lower sidebands (USB and LSB) in the FSK signal, where the group delay between the signals in the USB and LSB would be large due to the fiber dispersion. However, the group delay due to dispersion can be easily compensated by the optical delay in the balanced demodulator.

2 Optical FSK modulator

A $LiNbO_3$ optical FSK modulator consisting of parallel four optical phase modulators [3, 4] was used to generate optical FSK signals, as shown in Fig. 1. We apply a pair of rf-signals, which are of the same frequency f_m and have a 90° phase difference, to the electrodes RF_A and RF_B. Two sub Mach-Zehnder structures should be in null-bias point. An SSB suppressed-carrier signal, comprising one of the sideband components (USB or LSB), can be generated, when the optical phase difference induced by RF_C (ϕ_{FSK}, henceforth) is $\pm 90°$ [5]. Thus, the optical frequency of output lightwave can be switched by changing the induced phase at RF_C. By feeding an electric OOK signal, whose zero and mark levels correspond to $\phi_{FSK} = +90°$ and

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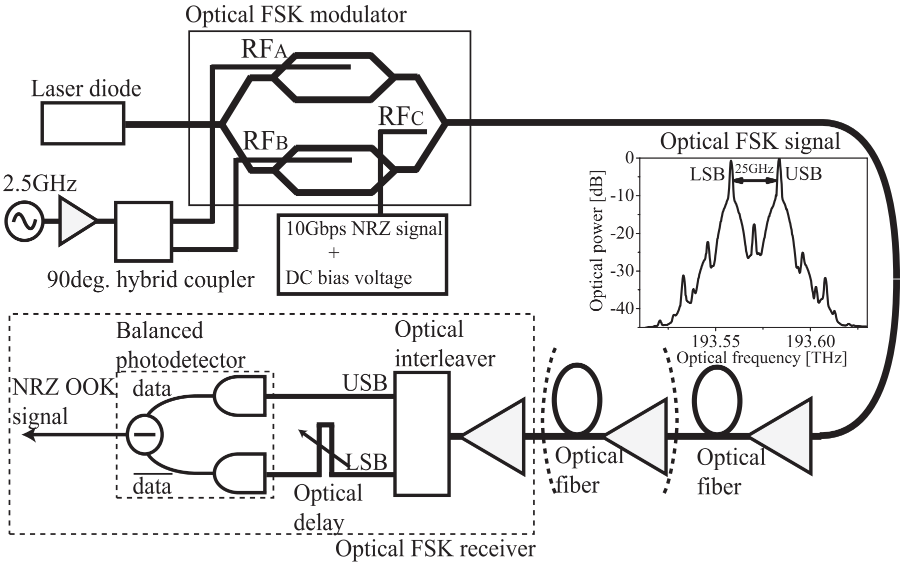

Fig. 1. Setup for optical FSK transmission and spectrum of optical FSK signal (inset).

$-90°$, to $\mathrm{RF_C}$, we can generate an optical FSK signal. When the bandwidth of the OOK signal is smaller than the rf-frequency f_m, the FSK signal can be demodulated by optical filters.

3 FSK transmission experiments

The experimental setup for optical FSK transmission via a single-mode-fiber (SMF) is shown in Fig. 1. The frequency deviation (frequency difference between USB and LSB components) was 25 GHz ($2f_m$). A 9.95 Gbit/s non-return-to-zero (NRZ) signal of $2^{23}-1$ psude random bit sequence was applied to $\mathrm{RF_C}$ of the modulator. The bit rate was smaller than f_m, so that the overlap between the USB and LSB components was negligible as shown in Fig. 1. Thus, we can convert the FSK signal to an OOK optical signal by using an optical interleaver which can discriminate the USB and LSB. The discriminated signal would be similar to a zero chirp NRZ OOK signal, because the Mach-Zehnder structures in the FSK modulator had balanced electrodes of coplanar waveguides constructed on an x-cut $LiNbO_3$ substrate.

We measured bit-error-ratio (BER) performance of FSK transmission, with balanced or single-ended detection. In the balanced detection, the two optical outputs discriminated by the interleaver were fed to a balanced photodetector. Thus, we can obtain 3 dB receiver sensitivity enhancement with respect to the single-ended detection where only one of the discriminated signals was fed to the photo detector. However, for the balanced detection, we should use an optical delay in the receiver in order to compensate the group delay difference between the USB and LSB. In this paper, we call this setup group delay compensated balance detection. The delay $|\Delta t|$ should be $\Delta\lambda LA$, where $\Delta\lambda = 2\lambda^2 f_m/c$, and λ is the wavelength of the laser diode. A, L and c are, respectively, the fiber dispersion, the length of the fiber and the speed of light.

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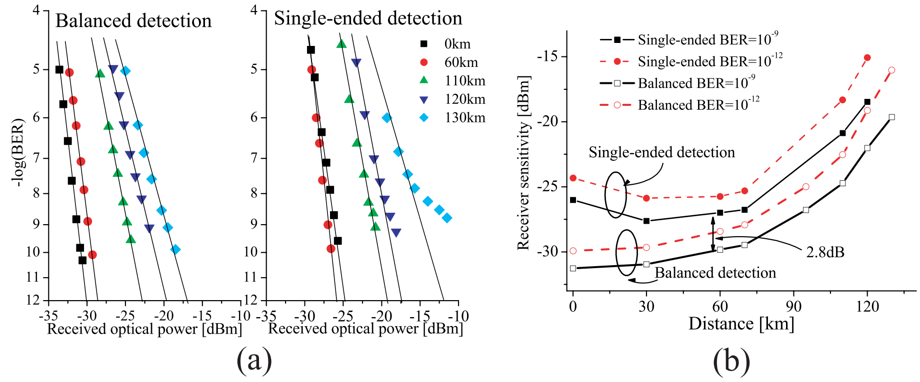

Fig. 2. BER curves (a) and receiver sensitivity versus fiber length (b)

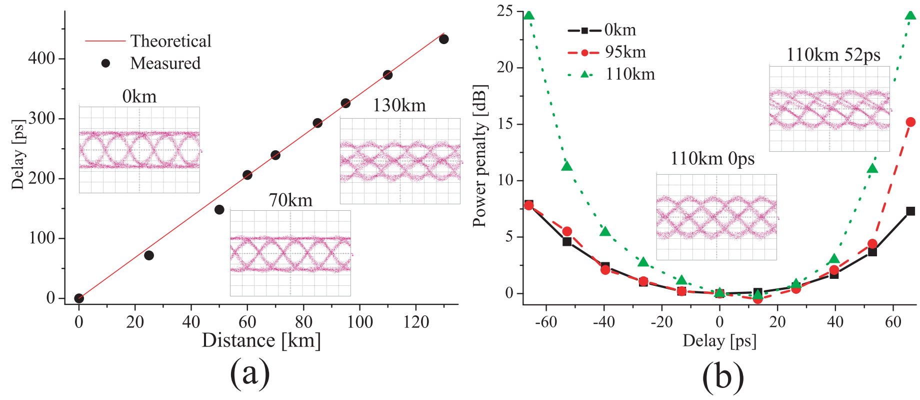

Fig. 3. Optimal delay for balanced detection (a) and tolerance of the delay (b)

Fig. 2 shows BER curves and receiver sensitivities. The results show that error-free transmission of 10 Gbit/s FSK-130 km SMF is possible, by using the group delay compensated balance detection, where the single-ended detection could not achieve error-free transmission with a 130 km SMF. As shown in Fig. 2 (b), we can obtain 2.8 dB negative penalty at 60 km (BER=10^{-9}) by using the balance detection, where this agrees well with the theoretical result (3 dB). When the length of the fiber was larger than 75 km, an EDFA was placed at the distance of 60 km from the FSK modulator.

Fig. 3 (a) shows the optimal optical delay for the delayed balance detection, as a function of the distance, where the experimental results agrees to the theoretical calculation. Eye-diagrams of 0 km (back-to-back), 70 km and 130 km are shown shown in insets of Fig. 3 (a). We measured the power penalty versus optical delay offset from the optimal condition, as shown in Fig. 3 (b). When the absolute value of the offset becomes large, the demodulated signal would be distorted due to the group delay difference between zero and mark levels, as shown in insets of Fig. 3 (b): eye-diagrams of 110 km transmission with 0 ps and 52 ps offsets. If the fiber length was shorter than 95 km, the delay tolerance for 3 dB penalty was about ±40 ps.

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4 Conclusion

Optical FSK transmission over a 130 km SMF at 10 Gbit/s was demonstrated by using the group delay compensated balance detection for high-speed optical FSK transmission, consisting of a balanced photodetector and an optical delay. The FSK signal was generated by a $LiNbO_3$ optical modulator comprising four phase modulators. The fiber dispersion effect was successfully compensated by an optical delay.

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