

LiNbO₃ high-Speed optical FSK modulator

T. Kawanishi, K. Higuma, T. Fujita, J. Ichikawa,
T. Sakamoto, S. Shinada and M. Izutsu

An optical frequency-shift-keying (FSK) modulator with a pair of Mach-Zehnder structures that can switch optical frequency is developed. The operation is demonstrated at a 10 Gbit/s FSK transmission conducted on a standard singlemode fibre of 60 km, where the FSK signal is demodulated by a fibre Bragg grating.

Introduction: In previous works, frequency-shift-keying (FSK) modulation for coherent optical systems was investigated to obtain enhanced receiver sensitivity [1, 2]. Recently, optical packet systems using FSK technique have received considerable attention. FSK is an effective scheme for optical labelling, where payload signals are transmitted by conventional intensity modulation and direct detection [3].

The merit of this FSK labelling is that an FSK transmitter generates the label information on the optical carrier frequency without affecting its intensity. The label information can be extract without affecting the payload signal. For this purpose, fast and wideband external FSK modulation technique is required, which has never developed. In previous works, FSK signal was generated by direct modulation of electric current in a laser light source [3, 4]. Thus, FSK bit rate is limited by the response of the laser. Parasitic intensity modulation in the direct modulation should be compensated by using an additional intensity modulator. The FSK bit rate generated by direct modulation was not higher than 1 GHz [4, 5].

Recently, however, we reported wavelength conversion using an optical single-sideband (SSB) modulator consisting of a pair of Mach-Zehnder structures [6, 7]. The wavelength of the output lightwave depends on RF-signal frequency and DC-bias voltage fed to the modulator, which can be electronically controlled. In this Letter, we propose an optical FSK modulator based on the SSB modulator, and demonstrate high-speed FSK transmission. Using this modulator, we can generate optical FSK signals with a simple setup. FSK transmission is experimentally demonstrated at 10 Gbit/s with a 60 km singlemode fibre. Using this technique, we can increase the number of the labels which depends on the FSK bit rate.

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, but the FSK modulator has an electrode (RF_C) for high-speed FSK signal, instead of a DC-bias electrode in the SSB modulator [6, 7]. When 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, frequency shifted lightwave can be generated at the output port of the modulator. A

sub-Mach-Zehnder structure of paths 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 paths 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 to each other. When the phase difference induced by RF_C is $\pm 90^\circ$, we can obtain carrier-suppressed single sideband modulation comprising one of the sideband components (USB or LSB). Thus, the optical frequency of output lightwave can be switched by changing the induced phase at RF_C . In the SSB modulator previously reported, the electrode for optical phase control was not designed for high-speed operation, so the switching time was limited by the response of the electrode. However, the FSK modulator has the electrode RF_C for a high-speed optical phase switch at the junction of a pair of sub-Mach-Zehnder structures. The amplitudes of USB and LSB are, respectively, described by $[1 + \exp(i\phi_{FSK})]/2$ and $[-1 + \exp(-i\phi_{FSK})]/2$, where (ϕ_{FSK} is the induced phase difference at RF_C , and $i\phi_{FSK} = 0^\circ$ corresponds to an optimal condition for USB generation. Thus, by feeding an NRZ signal, the zero and mark levels of which correspond to $i\phi_{FSK} = 0, 180^\circ$, to RF_C , we can generate an optical FSK signal, without any parasitic intensity modulation. The bandwidth for the FSK signal should be smaller than the RF-frequency f_m when the FSK signal is demodulated by optical filters.

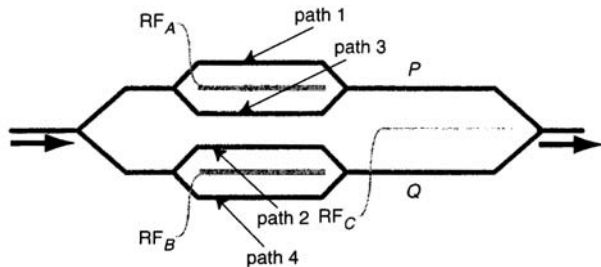


Fig. 1 Optical FSK modulator

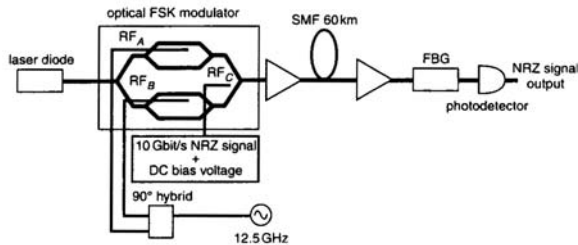


Fig. 2 Schematic diagram of experimental setup

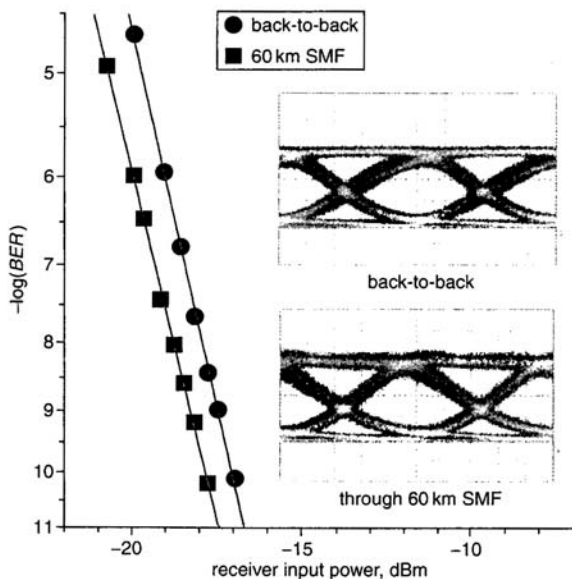


Fig. 3 Eye diagrams and bit error rates of demodulated NRZ signals for back-to-back and after 60 km transmission

Experiments: We fabricated an optical FSK modulator having an $LiNbO_3$ lightwave circuit with travelling-wave electrodes to obtain high-speed response, and measured bit error rate (BER) performance of FSK transmission. The bandwidth of the travelling-wave electrode for frequency switching was 18 GHz. As shown in Fig. 2, a fibre Bragg grating (FBG) was used to convert an FSK signal into an IM signal for demodulation. A 9.95 Gbit/s NRZ ($2^{31} - 1$ PRBS) signal was applied to RF_C of the FSK modulator. Fig. 3 shows BER curves and eye diagrams of 9.95 Gbit/s FSK for back-to-back, and after transmission through a 60 km singlemode fibre (SMF). The RF frequency f_m was 12.5 GHz. The results show that the eyes are clearly open and that error-free transmission of 10 Gbit/s FSK 60 km SMF is possible. Power penalties of 60 km transmission with reference to back-to-back at $-\log(BER)=9$ was -0.8 dB. We deduce that the negative penalty was due to the dispersion of the FBG.

Conclusion: We fabricated an optical FSK modulator consisting of a pair of Mach-Zehnder structures, and demonstrated FSK transmission at 10 Gbit/s with an SMF of 60 km. The modulator can shift the output optical frequency without affecting the output optical power.

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T. Kawanishi, T. Sakamoto, S. Shinada and M. Izutsu (*Basic and Advanced Research Division, Communications Research Laboratory, 4-2-1 Nukui-Kitamachi, Koganei, Tokyo 184-8795, Japan*)

K. Higuma, T. Fujita and J. Ichikawa (*New Technology Research Laboratories, Sunlitomo Osaka Cement, 585 Toyotomi, Funabashi, Chiba 274-8801, Japan*)

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