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# 10Gbit/s FSK transmission over 95 km SMF using an external optical FSK modulator

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**Abstract** *We demonstrate high-speed optical FSK transmission over a 95km SMF at 10Gbit/s using an integrated $LiNbO_3$ optical FSK modulator consisting of four phase modulators. FSK signal was demodulated by an optical interleaver.*

## 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 labelling, 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], which is based on optical single sideband (SSB) modulation technique [6]. In this paper, we demonstrate high-speed optical FSK transmission over a 95 km single-mode fibre (SMF) at 10 Gbit/s using an integrated $LiNbO_3$ optical FSK modulator, where the FSK signal was demodulated by an optical interleaver.

## 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 [6], but the FSK modulator has an electrode RFC 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 (fm) 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 RFC 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 $[1+i\exp(-i\phi_{FSK})]/2$ and $[1+i\exp(i\phi_{FSK})]/2$, where $\phi_{FSK}$ is the induced phase difference at RFC, and $\phi_{FSK}$ = 90˚ corresponds to an optimal condition for USB generation. Thus, by feeding an NRZ signal, whose zero and mark levels respectively correspond 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 RFC for high-speed optical phase switch at the junction of a pair of sub Mach-Zehnder structures.

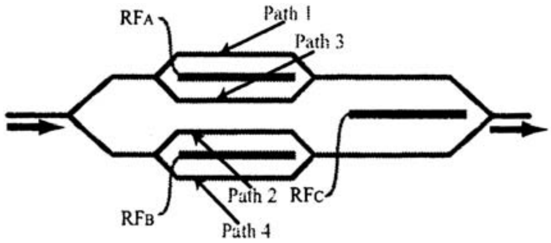


*Fig. 1 Schematic structure of optical FSK modulator*

## FSK transmission

Fig. 2 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 3dB bandwidths were 18 GHz. A pair of sinusoidal electric signals having 90˚ phase difference were applied to the electrodes $RF_A$ and

RFB, for generation of sideband components. The phase difference was controlled by using tunable delay lines. The signal frequency fm 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 on-off keying (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 chanel separation was 25 GHz.

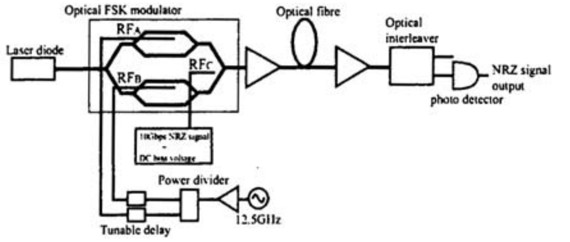


*Fig. 2 Setup for optical FSK transmission*

The demodulated signal should be similar to an NRZ OOK signal generated by a zero chirp optical intensity modulator (see Fig. 3), because the sub Mach-Zhender structures in the FSK modulator had balanced electrodes of coplaner waveguides, and were constructed on an x-cut $LiNbO_3$ substrate. We measured bit-error-ratio (BER) performance of FSK transmission. A 9.95 Gbps (NRZ $2^{31}$-1 PRBS) signal was applied to RFC of the modulator. Fig. 4 shows BER curves and eye-diagrams of 9.95 Gbps FSK for back-to-back, and after transmission through a 95 km SMF. The results show that the eyes are clearly open and that error-free transmission of 10 Gbps FSK-95 km SMF is possible. Fig. 5 shows power penalties as functions of transmission distance. Power penalty of 95km transmission with reference to back-to-back at BER=$10^{-12}$ was 1.7 dB.

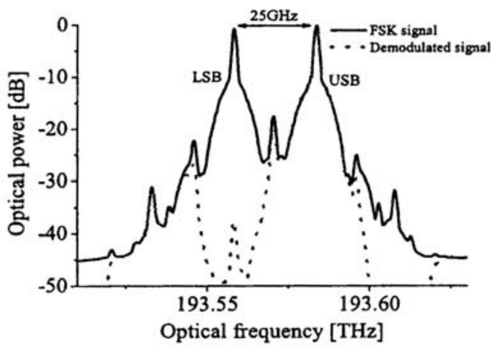


*Fig. 3 Optical spectra of FSK signal (solid line) and demodulated OOK signal (dotted line)*

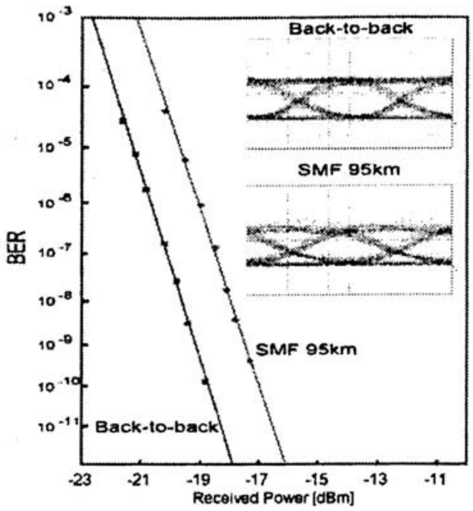


*Fig. 4 BER curves and eye-diagrams*

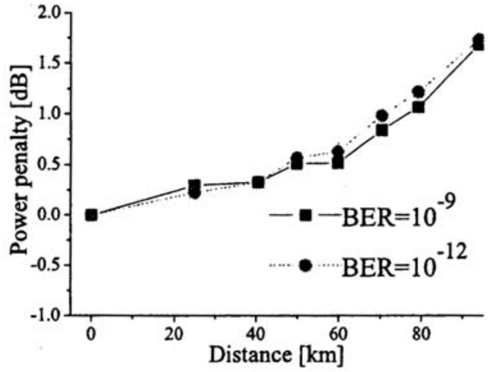


*Fig. 5 Power penalties versus distance*

**Conclusions**

We demonstrated high speed optical FSK transmission over a 95 km SMF at 10 Gbit/s using a $LiNbO_3$ optical FSK modulator consisting of four phase modulators. FSK signal was demodulated by an optical interleaver. 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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