A Novel Optical Frequency-Shift-Keying Transmitter Using Phase Modulator-Embedded Optical Loop Mirror

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Abstract: A novel OFSK transmitter based on a phase modulator-embedded optical loop mirror is proposed and experimentally demonstrated, which offers data-rate transparency and continuous tuning of the wavelength spacing and can be used in label swapping.

OCIS codes: (060.2330) Fiber optics communications; (060.2630) Frequency modulation

1. Introduction

Much attention has recently been focused on the optical frequency-shift-keying (OFSK). One obvious application aims at the long haul transmission. In this case, the wavelengths of the two optical frequencies are half of the data rate and the phase at each bit transition instant is continuous, thus forming the minimum shift-keying (MSK), which has the advantage of larger dispersion tolerance. This kind of transmitter has been demonstrated in [1] using specially designed modulator. Another important application of OFSK aims at realizing some special functions such as label swapping [2], data re-modulation in access networks [3] and so on, via utilizing its constant intensity in the time domain. In this case, the data rate transparency and tunability of the wavelength spacing is necessary in the transmitter design.

There are several methods to generate this kind of OFSK signals. In [2], the transmitter was realized by direct modulation of DFB laser followed by an EAM, but the bit rate was limited to 2.5 Gb/s due to the modulation response time of the commercially available directly modulated DFB lasers. In [3], a high-speed OFSK transmitter was demonstrated based on phase modulation followed by an optical delay interferometer (DI), but the data rate and the OFSK wavelength spacing were constrained by the fixed DI's frequency response, and the data had to be differentially pre-coded. These problems were solved in [4] where a high-speed OFSK transmitter was constructed based on polarization modulation in an optical phase modulator (PM). However, the signal's polarization has to be carefully controlled, which made the operation difficult.

In this paper, we propose and demonstrate a novel high-speed OFSK transmitter based on a PM–embedded loop mirror. It features data-rate transparency and continuous tuning of the wavelength spacing. The feasibility and performance of the transmitter were experimentally investigated. It may find applications in label swapping, data re-modulation in access network and so on.

2. Operation Principles

Fig. 1 illustrates the operation principle of the proposed OFSK transmitter. Two continuous-wave (CW) light beams (λ_1 and λ_2) with certain wavelength spacing are fed into the loop from different ports of the 3-dB coupler. Polarization controllers PC1 and PC2 were used to align the input light beams' polarization with the main axis of the PM to achieve the best phase modulation performance. The PM used is a commercially available product that is made from $LiNbO_3$ crystal and the driving radio frequency (RF) data signal is applied to the crystal via the traveling-wave electrodes. Therefore, the addition of the RF signal is directional, i.e. the light transmitted from port A to port B will be phase modulated by the applied signal, but not the case for the light transmitted in reverse direction. When there is no data signal applied onto the PM, we should adjust the polarization controller PC3 in the loop to make this loop work in "mirror" state.

When the input data symbol is "0", no voltage is applied to the PM. As a result, there is no phase shift induced to both optical carriers and the light with wavelength λ_1 will be reflected to the OFSK output port through the circulator. When the input data symbol is "1", a voltage V_π is applied to the PM. As described above, only the light propagating clockwise will experience the π phase shift. Thus, the loop will change from the "mirror" state to "through" state and the light with wavelength λ_2 will appear at the OFSK output port. Consequently, the output signal becomes an OFSK signal in which the data level on each optical carrier are complementary to each other and exhibits constant optical intensity. The optical isolator before laser diode (LD) LD2 is used to prevent the light reflection from affecting the LD2 lasing performance.

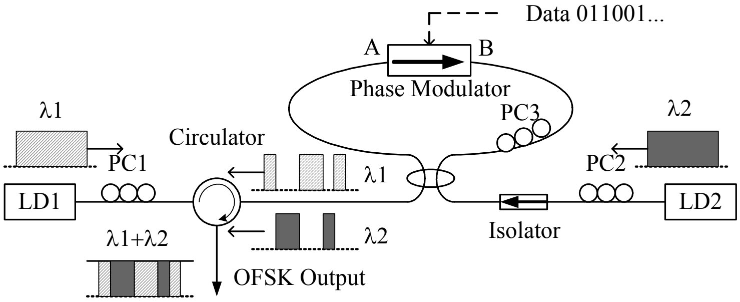

Fig. 1 Proposed OFSK transmitter design and operation principle

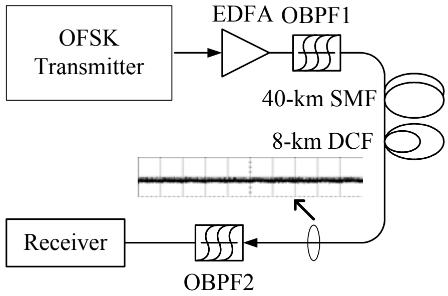

Fig.2 Experiment Setup. Inset shows the waveform of the OFSK signal after transmission

3. Experimental Demonstration

Fig. 2 shows the experimental setup where the OFSK transmitter part is similar to Fig. 1. The two optical frequencies are λ_1=1546.00 nm and λ_2=1546.60 nm with 0.60-nm spacing. The modulating signal applied to the PM was 10-Gb/s NRZ 2^{31}-1 PRBS data. Fig. 3 shows the captured waveforms of the individual wavelengths (λ_1 and λ_2) as well as the output OFSK signal ($\lambda_1 + \lambda_2$). The generated OFSK signal was then amplified by an EDFA to about 6-dBm and filtered by OBPF1 with 3-dB bandwidth of 1-nm to suppress the excessive ASE noise. The center of OBPF1 was set to be the middle wavelength (1546.30 nm) of the two input wavelengths. The amplified OFSK signal was then transmitted over 40-km SMF followed by an 8-km DCF for complete dispersion compensation. After transmission, it was observed that the constant-intensity envelope was preserved, as shown in the inset of Fig. 2. The received signal was filtered by OBPF2 with a 3-dB bandwidth of 0.2-nm for signal demodulation.

The BER performance of the proposed OFSK transmitter has been measured before and after transmission and compared with that of an ASK signal generated from a conventional intensity modulator. In both cases, the system performance of OFSK signal was comparable to the signal generated by an ASK transmitter and the demodulated OFSK signal exhibited negligible power penalty between back-to-back case and after 40-km transmission case. By tuning the wavelength spacing of the two optical carriers from 0.15 to 1-nm with 0.05nm step, we measured the power penalties of the demodulated signals with reference to the case of 0.6-nm wavelength spacing. The measurement results are shown in Fig. 4. For the wavelength spacing ranging from 0.3 to 1-nm, the power penalty is very small. However, when the wavelength spacing was tuned to be less than 0.3-nm, large power penalty was observed due to the interference between the two wavelengths. Furthermore, the proposed OFSK transmitter was characterized at different operating data-rates from 1-Gb/s to 10-Gb/s with 1-Gb/s step. The measured results shown in Fig. 5 prove that the proposed OFSK transmitter is data-rate transparent.

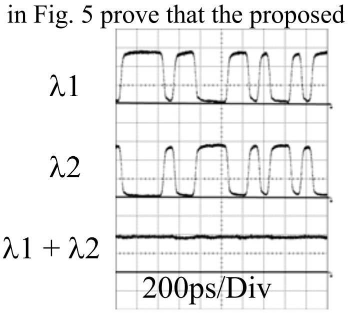

Fig.3 Measured waveforms of individual wavelengths and the composite signal

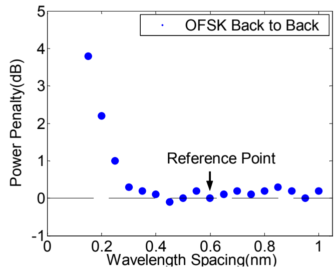

Fig.4 Power penalties for different wavelength spacing of demodulated OFSK signals

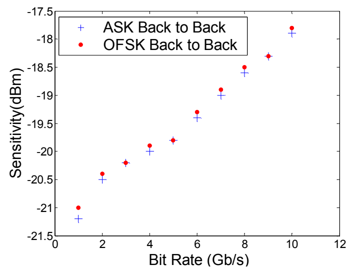

Fig.5 Receiver sensitivity of ASK and demodulated OFSK signals

4. Conclusion

We have proposed and experimentally demonstrated a novel OFSK transmitter based on a PM-embedded optical loop mirror, which features data-rate transparent and continuous tuning of the wavelength spacing. This transmitter design may find application in many areas, such as label swapping, data re-modulation and so on. This project was partially supported by a research grant from Hong Kong Research Grants Council (Project CUHK4106/05E).

References

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