A Novel Optical Frequency Shift Keying Transmitter Based on Polarization Modulation

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Abstract: We propose and experimentally demonstrate a novel optical frequency shift keying transmitter based on polarization modulation. It features at its data rate transparency and continuous tuning of wavelength spacing. The performance of the transmitter has been further experimentally characterized.

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1. Introduction

Optical frequency shift keying (OFSK) has recently been recognized as one of the best modulation formats for long haul optical transmission. Comparing with DPSK, NRZ and RZ modulation formats, OFSK showed the lowest sensitivity with respect to fiber non-linearity impairments [1]. Moreover, due to its constant intensity property, it could support orthogonal modulation with amplitude shift keying (ASK) and hence it has recently found applications in optical labeling [2], and data re-modulation [3] in optical networks. Besides, its demodulation can be easily realized by simple optical filtering.

Conventional OFSK transmitter was realized by direct modulation of distributed feedback (DFB) laser followed by an electroabsorption (EA) modulator [2]. However, the modulation bit-rate was limited (~2.5-Gb/s) by the modulation response of the DFB and the wavelength spacing between the two OFSK carriers was limited to about 0.3 nm due to limited driving current range. Such closely spaced OFSK carriers hindered precise signal demodulation and also further limited the modulation data rate as any overlapping between the spectra of the two carriers would induce severe crosstalk and signal beating. In [3], a high-speed OFSK transmitter was demonstrated based on phase modulation followed by an optical delay interferometer (DI). This scheme was able to operate at high-speed, but the data rate and the OFSK carrier spacing were determined by the fixed DI’s frequency response. Besides, the data has to be differentially pre-coded. In this paper, we propose and demonstrate a novel high speed OFSK transmitter based on polarization modulation. It can operate at any data rate, and the OFSK carrier spacing can be continuously tuned. No data pre-coding is needed.

2. Transmitter Design and Operation Principle

Fig. 1. Proposed OFSK transmitter design and operation principle
Fig. 1 illustrates the configuration and operation principle of the proposed OFSK transmitter. Two CW light beams (λ1 and λ2) with small wavelength spacing are combined and fed into an optical phase modulator (PM). Before they are fed into the PM, the polarization of each of them is adjusted by a polarization controller (PC) such that (1) they are linearly polarized and are 45° relative to the principal axes of the PM; and (2) they are orthogonal to each other. Under these conditions, each of these two optical carriers undergoes polarization modulation and becomes a polarization shift keying (PolSK) signal [4]. As their input polarizations are orthogonal to each other, the two generated PolSK signals would behave complementarily and thus the composite signal after a polarizer becomes an OFSK signal with constant intensity envelope.

To illustrate the principles in more details, we may decompose the 45° polarization of each of the input optical carriers into two equal components, one in nx direction and the other in nz direction. When the input data symbol is “0”, no voltage is applied to the PM. Therefore, there is no phase shift induced to both optical carriers, as shown by “0” Polarization of λ1 and λ2 in Fig. 1. When the input data symbol is “1”, a voltage Vπ is applied to the PM. Such applied voltage induces π phase shift in nz-component but no phase shift in nx-component, as shown by “1” Polarization of λ1 and λ2 in Fig. 1. This leads to 90° rotation of the polarization of each optical carrier, thus it looks like that their polarizations are exchanged. By aligning a polarizer to one of the polarization component of the combined signal (λ1+λ2), the output signal becomes an OFSK signal in which the data level on each optical carrier behaves complementarily. As shown in Fig. 1, an input data symbol “1” will lead to high level on λ2 and low-level on λ1 at the output of the aligned polarizer, and vice versa for an input data symbol “0”. In practice, there may be some residual phase shift in nx component, whose value is about one third of phase shift in nz component [4] in a commercial PM. To solve this, the applied voltage to the PM can be increased to about 1.5 Vπ so as to obtain π phase shift difference between the two components.

3. Experiments and Results

Fig. 2 shows the experimental setup to characterize the performance of our proposed OFSK transmitter. Two CW light beams (λ1=1553.40nm and λ2=1554.01nm) launched by two DFB lasers with 0.61-nm spacing were combined by 50/50 fiber coupler and fed into an optical phase modulator (PM). Their polarizations were optimized by individual PC before entering the PM to satisfy the above stated requirements, i.e. mutually orthogonal, linearly polarized and 45° relative to the principal axes of the PM. The combined signal was then polarization-modulated by a 10-Gb/s NRZ 2^31-1 pseudo random binary sequence (PRBS) via the PM. At the output of the PM, another PC was adjusted such that “0” polarization of λ1 (“1” polarization of λ2) was exactly aligned to the polarizer, and the desired OFSK signal was generated at the output of the transmitter. Fig. 3 shows the captured waveforms of λ1, λ2, and the combined signal (λ1+λ2). It is shown that both input wavelengths exhibited complementary data modulation with excellent extinction ratios while the combined signal showed constant intensity envelope. Such generated OFSK signal was then amplified by an EDFA to about 4 dBm and filtered by an optical bandpass filter (OBPF1) with a 3-dB bandwidth of 0.8 nm to suppress the excessive amplified spontaneous emission (ASE). The center of the optical filter passband was set to be the middle wavelength (1553.70nm) of two input wavelengths. The amplified OFSK signal was then transmitted over a piece of 40-km standard single mode fiber (SMF) and was completely dispersion-compensated by a piece of 8-km dispersion compensating fiber (DCF). At the end of the transmission link, it was observed that the constant-intensity envelope of the OFSK signal was preserved. The received signal was
filtered by an optical grating filter with a 3-dB bandwidth of 0.2 nm for signal demodulation before being detected by a 10-Gb/s PIN receiver.

We have further experimentally characterized the performance of the proposed OFSK transmitter, and compared with the performance of a conventional ASK signal, as a benchmark. Fig. 4 shows the measured transmission performance between a 10-Gb/s ASK signal using a conventional intensity modulator and an 10-Gb/s OFSK signal generated by our proposed transmitter. It is observed that the demodulated OFSK signal exhibited negligible power penalty for both the back-to-back case and after 40-km transmission, showing that the signal generated by this OFSK transmitter had excellent extinction ratio and is comparable to the signal generated by an ASK transmitter.

We then varied the spacing of the two input wavelengths as well as the operating bit rate to further investigate the performance of our proposed transmitter. The wavelength spacing was tuned from 0.1 nm to 1 nm in 0.05-nm step and the power penalties with reference to the case of 0.6-nm wavelength spacing were measured; and the results are shown in Fig. 5. For any wavelength spacing smaller than 0.3 nm, large power penalty was observed. It was due to interference between the two data spectra of the input wavelengths. As the wavelength spacing increased from 0.3 nm to 1 nm, such interference became less significant and nearly negligible power penalty was observed in this wavelength range. However, any further increase in wavelength spacing would introduce more power penalty due to signal distortion by excessive filtering at OBPF1 and the possible walk-off effect induced by the fiber dispersion. Nevertheless, as larger wavelength spacing means lower spectrum efficiency, thus the optimal wavelength spacing for the OFSK signal was found to be within the range from 0.3 nm to 0.6 nm and was continuously tunable. Furthermore, the proposed OFSK transmitter was characterized at different operation data rates and the measured receiver sensitivity was plotted in Fig. 6. It is shown that the generated OFSK signal at different data rates achieved comparable performance as compared with that of a typical ASK signal. Thus, this proves that our proposed OFSK transmitter is data-rate transparent.

4. Summary
We have proposed and experimentally demonstrated a novel optical frequency shift keying transmitter, which is based on polarization modulation. The transmitter is data rate independent and is capable of continuous tuning of wavelength spacing. Experimental characterization of the transmitter performance has been presented.

References: