Simultaneous Demodulation and Slow-light Delay of DPSK Signals at Flexible Bit-Rates Using Bandwidth-Tunable SBS in Optical Fibre

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Abstract

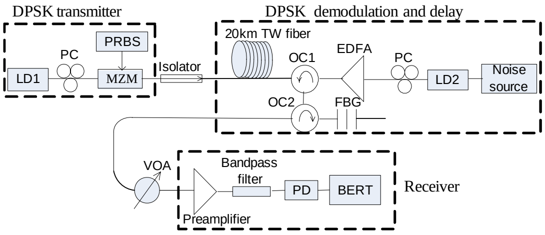
Introduction

Differential phase shift keying (DPSK) is an attractive modulation format because of its high tolerance to both amplified spontaneous emission (ASE) noise and fibre nonlinear impairments [1]. Different optical DPSK demodulation techniques have been proposed, such as 1-bit-delay Mach-Zehnder interferometer (MZI) [2], birefringent fibre loop [3] and Gaussian-shaped fibre Bragg grating (FBG) [4]. Among them, the FBG-based demodulator is the most stable and simplest one. However, once the FBG has been fabricated, it can only be used to demodulate DPSK signals with fixed bit-rate and wavelength. Furthermore, it is very difficult to demodulate low-speed DPSK signals based on the present FBG technology.

Stimulated Brillouin scattering (SBS) in fibre has been proposed as an active optical filter [5], whose central wavelength, bandwidth and profile are largely tunable by changing the wavelength, spectral-width and shape of the Brillouin pump. Therefore SBS-based filter is expected to demodulate DPSK signals at flexible bit-rates and wavelengths. On the other hand, recently SBS is extensively used to slow down the group velocity of light for potential data buffering [6-9]. In this paper, we propose the use of the bandwidth-tunable SBS to simultaneously demodulate and delay DPSK signals at flexible bit-rates. The sensitivities and delay-times of 10-Gb/s and 2.5-Gb/s DPSK signals after the SBS-based demodulator and delay-line are measured for different Brillouin pump power levels. For a 10-Gb/s DPSK signal, the best sensitivity and the maximal delay-time with error-free operation (BER<10^{-9}) after SBS are -32.1 dBm and 81.5 ps, respectively. The values are as high as -36 dBm and 205 ps for a 2.5-Gb/s DPSK signal.

Experimental setup

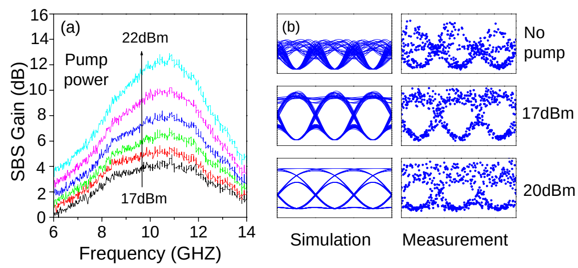
Fig. 1 shows the experimental set-up. The DPSK transmitter consists of a laser diode (LD1) operating at 1548.26nm followed by a polarization controller (PC), and a Mach-Zehnder modulator (MZM) driven by a 2^{23}-1 PRBS generator. The DPSK signal is then launched into the SBS-based demodulator and delay-line. The SBS gain medium is a 20-km long TrueWave^{TM} (TW) fibre with ~10.75GHz Brillouin frequency shift. The SBS pump source is a directly



modulated laser diode (LD2), whose wavelength can be precisely adjusted through temperature control. The pump LD is modulated by a Gaussian noise source (Tektronix AFG3252), and subsequently boosted by a high power erbium-doped fibre amplifier (EDFA). The pump spectral bandwidth can be tuned by varying the peak-to-peak voltage of the Gaussian noise. After the SBS gain medium, the demodulated and delayed DPSK signal is filtered using a 0.1-nm bandwidth flat-top FBG to minimize crosstalk between Rayleigh backscattering of the broadband pump and the signal. The receiver consists of an optical preamplifier, a tunable optical filter, a photo-detector (PD) and a bit-error-rate tester (BERT). A variable optical attenuator (VOA) is used in order to tune the received optical power for the BER measurement.

Results and discussions

Firstly, we demonstrate the demodulation and delay of the 10-Gb/s DPSK signal. Fig. 2(a) shows the SBS gain spectra at different pump power levels measured by coherent heterodyne technique for an 8-GHz pump spectral bandwidth. Note that the Gaussian profile of the SBS gain is particularly suitable for DPSK demodulation. When the pump power is increased from 17 dBm to 22 dBm, the SBS gain bandwidth is decreased from 7 GHz to 3.5 GHz, which is very



convenient for finely optimizing the DPSK signal demodulation, as the filtering bandwidth is an important parameter for DPSK demodulation. Fig.2(b) shows the demodulated eye diagrams of the 10-Gb/s DPSK signal at different pump power levels both in numerical simulations and experimental measurements. In the simulations, we did not take into account the noise contribution, which leads to slight differences from the experimental results. When the pump is turned off, the DPSK signal is mainly distorted by the FBG, whose bandwidth and shape are not optimized for DPSK demodulation. When the pump power is 17 dBm, corresponding to a 7-GHz gain bandwidth, the DPSK signal is successfully demodulated to a duobinary format. For a 20-dBm pump power, the SBS gain bandwidth is decreased to 5 GHz. Such a narrow bandwidth induces pattern-dependent distortions of the demodulated signal.

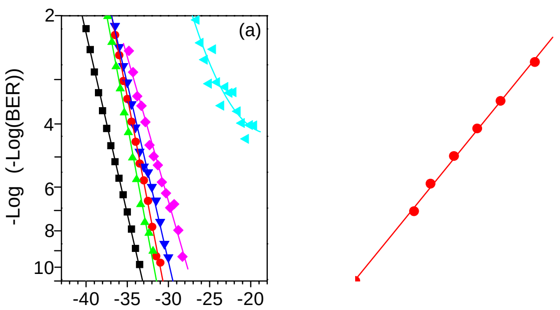


Fig. 3 BER [illegible]
10-Gb/s DPSK [illegible]

Fig. 3(a) shows the BER versus the received power of the demodulated 10-Gb/s DPSK signal for various pump power levels. Measured sensitivities at a BER = 10^{-9} are compared with back-to-back (BtB) sensitivity of a 10-Gb/s NRZ signal. The DPSK signal power is set at 5 dBm to improve the signal-Rayleigh noise ratio. With an 18-dBm pump power that results in 6.5-GHz gain bandwidth, one can obtain the best demodulation performance. The sensitivity after the demodulation is -32.1 dBm. Increasing the pump power reduces the SBS gain bandwidth, thus distorting the signal and degrading the sensitivity. When the pump power is increased up to 22 dBm, the demodulated DPSK signal is strongly distorted, and error-free operation can not be obtained. On the other hand, the SBS gain also induces DPSK signal delay, which increases with the pump power, as shown in Fig. 3(b). The insets are the demodulated eye diagrams of the DPSK signal at 18 and 21-dBm pump power, respectively. The delay-time is linearly increased with the on-off peak signal gain. The maximal delay-time with error-free operation is as high as 81.5 ps, which is to our knowledge the best result for 10-Gb/s signals. In addition, our result is much better than that obtained with a 1-bit-delay demodulation technique [9]. Because the SBS gain acts as a narrow-band Gaussian filter, the input DPSK signal can be transformed into duobinary signal [4]. Thus a strong distortion of the demodulated DPSK signal could occur through SBS based slow-light using a 1-bit delay demodulator [9]. In our case, we realized direct phase-to-amplitude conversion using SBS effect; therefore the distortion is significantly reduced.

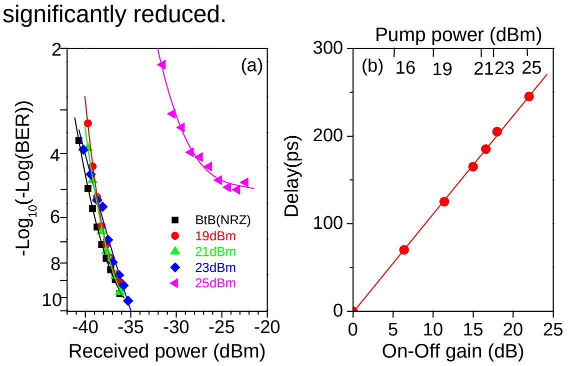


Fig. 4 BER [illegible]
2.5-Gb/s DPSK [illegible]

Finally, we measured BER and delay performances for 2.5-Gb/s DPSK signal, as shown in Fig. 4. The BER measurement has been obtained by keeping our 10-Gb/s PIN-FET photodiode. By tuning the SBS gain bandwidth, the 2.5-Gb/s DSPK signal can be successfully demodulated. For a 3.5-GHz pump spectral bandwidth, when the pump power is tuned to 21 dBm (corresponding to ~1.7GHz gain bandwidth), the sensitivity (at BER=10^{-9}) reaches the optimum value of -36 dBm. The maximal delay with error-free operation is 205 ps. Based on the same technique, one can demodulate and delay lower-speed DPSK signals (at 622Mb/s for example), which can not be realized by Gaussian-shaped FBGs. 40-Gb/s and higher-speed DPSK signals can also be demodulated and delayed by further increasing the SBS gain bandwidth using multiple Brillouin pumps [7].

Conclusions

For the first time, bandwidth-tunable SBS is proposed to simultaneously demodulate and delay DPSK signals at flexible bit-rates. A maximal delay-time of 81.5 ps with error-free operation (BER < 10^{-9}) has been obtained, which is to our knowledge the best result for 10-Gb/s signals. Direct demodulation of DPSK signals using SBS filtering effect has been shown very suitable for slow-light and system applications.

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