80-GB all-optical serial-to-parallel convertor for QPSK signal based on cascaded phase modulators and optical filters

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An all-optical serial-to-parallel converter (SPC) utilizing two cascaded phase modulators and optical band-pass filters (OBPFs) is experimentally investigated and applied to demultiplex an 80-GBd optical time-division multiplexing (OTDM) return-to-zero (RZ) differential quadrature phase-shift keying (QPSK) signal. Two 40-GBd OTDM tributaries are error-free demultiplexed with a power penalty of approximately 4 dB in the worst case. With its advantages of compact structure, high speed, low power penalty, simultaneous two-tributary operation, and no assistance from a light source, the SPC has potential for use in future OTDM networks. However, the performance of the SPC still needs improvement.

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The optical time-division multiplexing (OTDM) technique is seen as a very attractive candidate for increasing the bit-rate per wavelength channel further[1]. An all-optical serial-to-parallel converter (SPC) with multi-tributary demultiplexing capability and low power consumption is a key technique for OTDM networks. Most reported OTDM demultiplexers are designed for OTDM return-to-zero (RZ) on-off keying (OOK) signal and are not phase-preserved. Other reported demultiplexers, including those based on either electro-optical on-off gates utilizing electro-absorption modulator (EAM)[2], phase modulator (PM)[3], Mach-Zehnder modulator (MZM)[4], and nonlinear effects, such as cross-phase modulation (XPM)[5] and four-wave mixing (FWM), are also incapable of multi-channel processing[6]. Thus, along with the application of multi-level modulation formats, such as differential quadrature phase-shift keying (DQPSK) in OTDM systems[1,7], the development and investigation of schemes that are capable of demultiplexing, such OTDM signals with phase-preserving and multi-tributary processing capabilities, are necessary.

In this letter, an all-optical SPC that uses two cascaded PMs and optical band-pass filters (OBPFs) is experimentally investigated for optical quadrature phase-shift keying (QPSK) signals. We demonstrate the application of the SPC for the simultaneous demultiplexing of two 40-GB base-rate OTDM tributaries from an 80-GB OTDM RZ-DQPSK signal. Error-free performances were obtained for both base-rate tributaries. The power penalty was approximately 4 dB in the worst case. The SPC features a compact structure, high speed, low power penalty, and simultaneous two-tributary operation capacity, without assistance from a light source. With the possible capability of cascading such SPCs to extract more OTDM tributaries simultaneously, the proposed scheme has potential for use in future OTDM networks.

Figure 1 shows the experimental setup of the SPC for the demultiplexing of an 80-GBd OTDM RZ-DQPSK signal. An optical pulse train centered at 1 549.65 nm with a repetition rate of 40 GHz and a full-width at half-maximum (FWHM) of 8 ps was generated using an EAM driven by a 40-GHz sine signal. The pulse train was then linearly compressed into a FWHM of 3.5 ps by using a PM driven with a 40-GHz electrical sine signal with amplitude of $1.4V_\pi$ and a piece of 40-m dispersion compensated fiber (DCF, D=−134 ps/(nm·km) at 1 550 nm). Then, the pulse train was launched into a dual-parallel MZM (DPMZM) for QPSK modulation. The electrical I and Q tributaries were obtained from the positive and negative outputs of a 40-GHz pattern generator with a pattern length of 2^7-1 and a relative delay of 63 bits for decorrelation, respectively. After amplification, the 40-GBd optical RZ QPSK signal was time-division multiplexed through a delay-line based optical multiplexer into an 80-GBd OTDM RZ-DQPSK signal.

Prior to the application of the SPC, a 3-nm OBPF was first applied as a pre-filter to suppress part of the OTDM signal spectrum and potentially increase the optical signal-to-noise ratio (OSNR) of the two demultiplexed OTDM tributaries. The performance of the blue-shift and red-shift tributaries will be degraded if no suppression is applied because of spectrum overlapping. The SPC, which consisted of a 3-nm OBPF as a pre-filter, two PMs, and a dual-output optical filter (Finisar® waveshaper, 4000 s), was used for OTDM demultiplexing. The two cascaded PMs (V_π >10 V at 40 GHz), which were driven by two 40-GHz, 30-dBm (approximately $2V_\pi$) synchronized electrical sine waves, were applied to induce the maximum positive and negative chirps to the adjacent OTDM tributaries, respectively. The waveshaper, which was centered at 1 550.86 nm (port 1) and 1 548.03 nm (port 2) with an optimized bandwidth of 0.7 nm each, was used to simultaneously extract the two frequency-shifted OTDM tributaries.

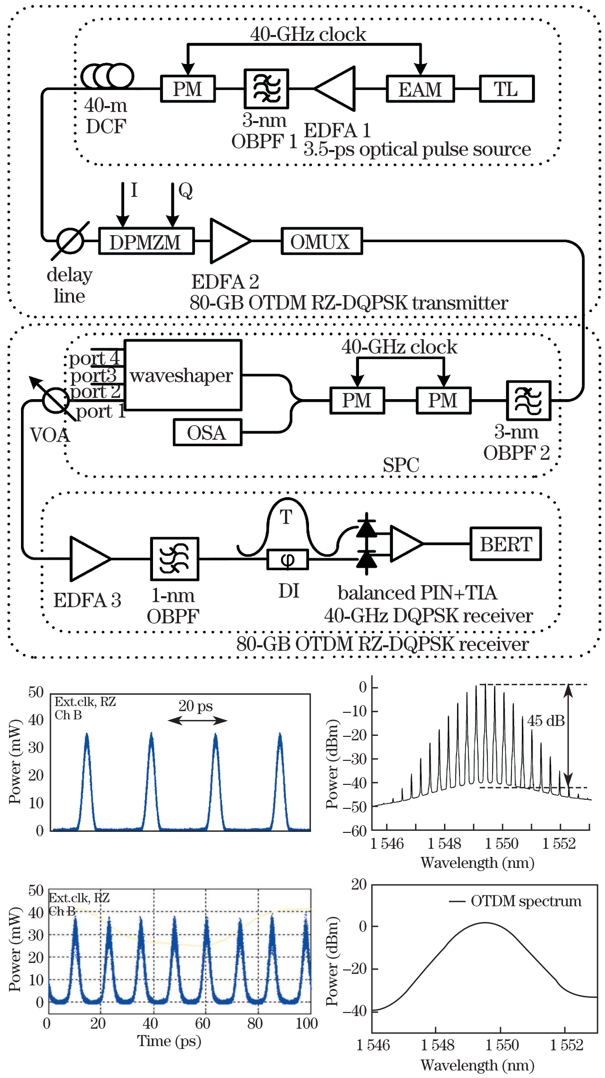

Fig. 1. Experimental setup. Insets: eye-diagrams and optical spectra of the short pulse train and OTDM signal.

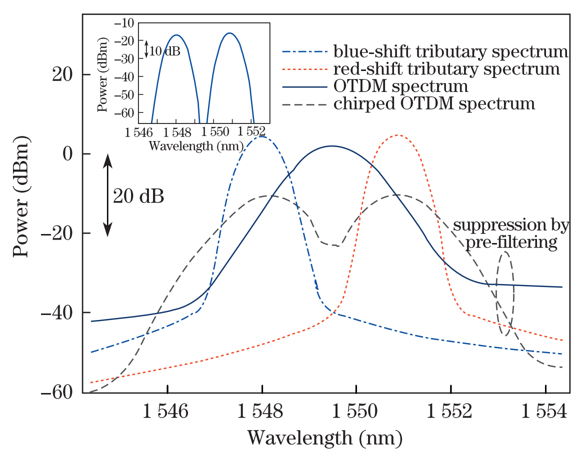

Fig. 2. (Color online) Measured optical spectra (resolution of 0.5 nm). Inset: filter shapes of the waveshaper.

Given that the chirps induced in all the symbols of the same OTDM tributary are the same, the phase information will be preserved during this stage. It should be noted that the filter can be replaced with an arrayed waveguide grating (AWG)[8] for compactness and cost-effectiveness when the induced chirp sufficiently separates the two OTDM tributaries. If the number of OTDM tributaries is greater than 2, a parallel cascade of the SPCs can be used to demultiplex all the tributaries[9].

The two demultiplexed OTDM tributaries were further demodulated using an optical delay interferometer (DI) and then sent for bit error-rate (BER) testing. It should be noted that no pre-coding was applied on the transmitter, and the BER tester was programmed to receive the expected data.

The insets of Fig. 1 show the optical eye-diagrams and spectra of the short pulse train and the 80-GB OTDM RZ-DQPSK signal. The OTDM signal spectrum had a 3-dB bandwidth of 1.2 nm.

Figure 2 shows the evolution of the OTDM spectrum. All the curves were measured and plotted with a resolution of 0.5 nm to clearly observe the separation between the spectra of the red-shift and blue-shift tributaries. After pre-filtering and cascading the two PMs, the spectrum was broadened into a 3-dB bandwidth of 2.63 nm. The blue-shift and red-shift components were clearly separated and extracted using a Gaussian-shaped dual-output filter. The inset of Fig. 2 illustrates the filter shapes of the dual-output filter (waveshaper).

Figure 3 illustrates the BER performance of the two demultiplexed 40-GBd base-rate OTDM tributaries. Error-free performances were achieved for both tributaries. For the 40-GBd RZ-QPSK signal under back-to-back (B2B) configuration, the sensitivities (at BER=1×10^{-9}) for I and Q tributaries were -29.29 and -28.98 dBm, respectively. On the other hand, for the demultiplexed OTDM tributaries with SPC for demultiplexing, the sensitivities (at BER=1×10^{-9}) were -25.62 dBm (red-shift, I tributary), -25.75 dBm (red-shift, Q tributary), -26.28 dBm (blue-shift, I tributary), and -24.91 dBm (blue-shift, Q tributary). The power penalty was approximately 4 dB in the worst case (blue-shift, Q tributary). The insets of Fig. 3 show the demultiplexed and demodulated optical eye-diagrams of the two OTDM tributaries, as well as the corresponding electrical eye-diagrams. The amplitude jitter of the optical eye-diagrams, which are the main causes of power penalty, originated from the

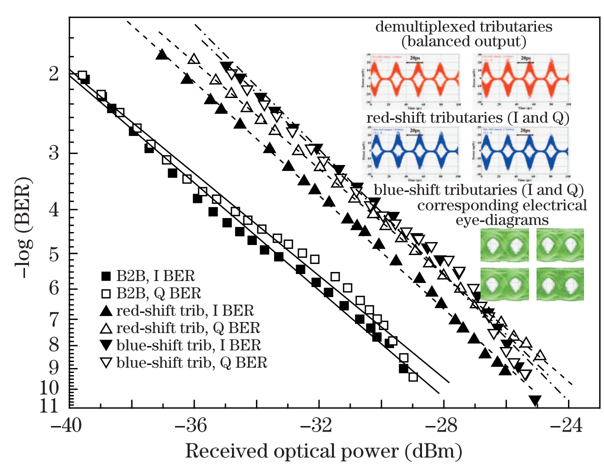

Fig. 3. (Color online) Measured BER results for the two demultiplexed OTDM tributaries. Insets: Demultiplexed and demodulated optical eye-diagrams and corresponding electrical eye-diagrams.

crosstalk between the two demultiplexed OTDM tributaries caused by a certain amount of spectrum overlap, which may be improved through strict pre-filtering or by inducing larger chirps. However, the SPC performance still requires further improvements.

In conclusion, we demonstrate and investigate an optical SPC for QPSK signal based on two cascaded PMs and OBPFs through an 80–40 GBd OTDM demultiplexing experiment. Error-free performances are achieved for both simultaneously demultiplexed OTDM tributaries. The power penalty is approximately 4 dB in the worst case. The proposed SPC features a compact structure, high speed, simultaneous two-channel operation, and cascadability, without any assistance from a light source. Such advantages indicate that the potential of the proposed scheme for use in future OTDM networks. However, the SPC performance still requires further improvements.

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