

DWDM-TO-OTDM CONVERSION USING A MULTIWAVELENGTH FEMTOSECOND PULSE GENERATION IN RAMAN COMPRESSION

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ABSTRACT— In this paper, we proposed the dense wavelength-division-multiplexing (DWDM) to optical time-division-multiplexing (OTDM) optical data format conversion is based on a Raman amplification based multiwavelength pulse compressor(RA-MPC). The optical data conversion from 4×40 -Gb/s DWDM channels to one 160-Gb/s OTDM channel by using the four wave mixing (FWM) effect in a highly nonlinear fiber (HNLF) and the power penalties of less than 1 dB. The pulse width-tunable picoseconds multi-wavelength pulse generation at 40 Gb/s by Raman amplification-based multiwavelength pulse compressor (RA-MPC) flexible functions. In this compression technique with pulse width tunability is required in order to adjust the pulse width for the formation of bit-rate variable OTDM channels. The pulse width of the compressed pulses can be simultaneously controlled by adjusting Raman pump power.

KEYWORDS — DWDM, OTDM, RA-MPC, FWM, HNLF.

I. INTRODUCTION

High speed Optical signal processing (OSP) has been broadly recognized as one of the enabling technologies to advance the future optical networks due to its possibility of ultrahigh bit rate and parallel operations, which are based on wavelength-division-multiplexing (WDM) and optical time-division-multiplexing (OTDM). All-optical format conversion from wavelength division multiplexing (WDM) to optical time division multiplexing (OTDM) is one of the important elements in all-optical networks. The WDM and OTDM techniques with their own advantages could bring the transmission capacity to terabit-per-second regime. WDM to optical time-division-multiplexing (OTDM) conversion has previously been demonstrated using semiconductor optical amplifier (SOA) [1] technology as well as using the nonlinear optical loop mirror (NOLM) [2]. The SOA technology has a limited frequency response and even at 40 Gb/s, it is difficult to obtain short enough pulses at the output to constitute a RZ signal. The use of mode-locked ring lasers is restricted in terms of cost, stability, and wavelength tunability, regardless the number of wavelengths. Super-continuum (SC) has often been utilized to generate multi-channel short pulse sources. However, this technique requires specialty nonlinear fibers and WDM filter for spectrum slicing [3]. Multi-channel pulse sources are also generated by using nonlinear optical loop mirror (NOLM). The NOLM is in general, not suitable for wavelength conversion, since the pulses that induce cross-phase modulation (XPM) have to be very short

Compared to the bit slot to avoid crosstalk due to unwanted XPM from the high average power. Previous DWDM-OTDM demonstrations are based on a variety of techniques with different degrees of complexity. However, it is difficult to realize pulse width tunability in picoseconds pulsewidth range. Recently, adiabatic soliton compression techniques have attracted much attention to generate high-quality short width pulse trains in the order of a few

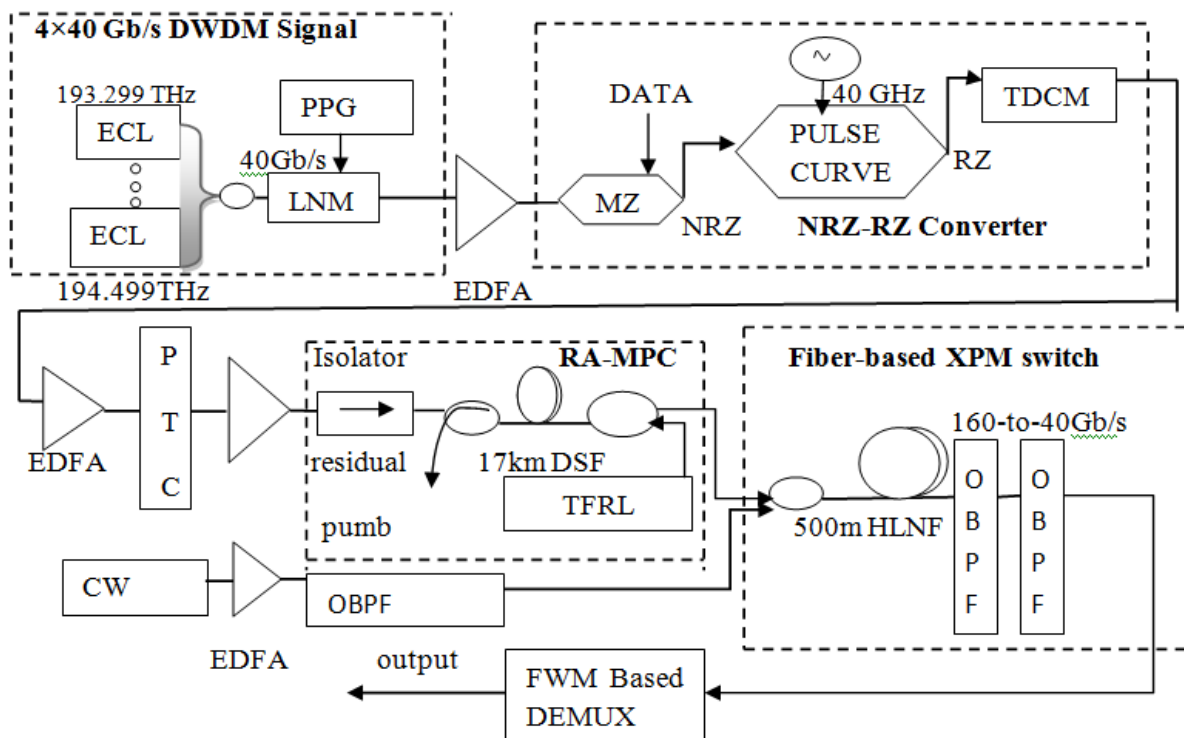
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picoseconds. Mainly, there are two types of techniques for adiabatic soliton compression. The first technique is gradually decreasing the dispersion value along the fiber by using dispersion profiled fibers, such as dispersion decreasing fiber (DDF), comb-like dispersion profiled fiber (CDPF) and step-like dispersion profiled fiber (SDPF). However, this technique requires special fibers with optimized dispersion profiles. As a simpler alternative, the second technique is using a distributed Raman amplifier (DRA) to increase the peak power of the soliton pulse during the pulse propagation in an anomalous dispersion fiber. This technique is possible to tune the pulse width of compressed pulse in the picosecond range by control of the Raman pump power. Recently, we have demonstrated the compression for multi-wavelength pulse trains at bit rate of 10 Gb/s by using a Raman amplification-based adiabatic soliton compressor [4] and its application to NRZ-to-RZ data format conversion with picosecond pulse [5], all-channel OTDM demultiplexing [6]. It would be flexible for bit-rate with the OTDM demultiplexing when the multi-wavelength pulse can be tuned. There is range of methods for temporally compressing optical pulses that is reducing the pulse duration. Naturally, such methods start in the picosecond or femtosecond region that is already in the system of ultra short pulses. In this paper, we propose a Raman amplification-based multiwavelength pulse compressor (RA-MPC). Four conventional WDM 40 GHz synchronous pulses are simultaneously compressed to less than 3.0 ps. Then, to verify the capability for full demultiplexing of 160 GB/s OTDM signal, the WDM synchronous compressed pulses are parametric interacted successively with four 40 Gb/s. Clear eye patterns and error-free operations are achieved for all demultiplexed channels. Less than 1 dB penalties from the back-to-back are obtained with 0.2 dB sensitivity variation among demultiplexed channels. The use of RA-MPC offers two main advantages: (1) high-power output which is desired in many applications, especially in fiber parametric gates, (2) femto second pulsewidth tunability by control of Raman pump power, which makes our proposed system potential for bit-rate flexible demultiplexing of OTDM signals up to 320 GB/s.

II. THE EXPERIMENTAL SETUP AND OPERATION PRINCIPLE

The experimental setup operation and principle of 4×40 Gb/s DWDM channels to one OTDM channel conversion is described in Fig. 1. The most straightforward intensity modulated format is NRZ. A combined four 40 Gb/s DWDM nonreturn-to-zero (NRZ) data.



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Fig. 1. Schematic diagram of principle and experimental setup for 4×40 Gb/s DWDM channels to one OTDM channel.

signals at wavelength of 194.499 THz (ch1), 194.100 THz (ch2), 193.700 THz (ch3), and 193.299 THz (ch4) with channel spacing of less than 100GHz were produced by using four external cavity laser diodes (ECLs). External Cavity Diode Lasers (ECL) and Laser Accessories offer wide coverage of the red and near infrared portions of the spectrum with true seamless mode hop-free tunability and single mode performance. A LiNbO₃ modulator (LNM) driven by electrical NRZ data from a pulse pattern generator (PPG). Lithium niobate (LiNbO₃) external modulators provide both the required bandwidth and the equally important means for minimizing the effects of dispersion. Unlike direct modulation of a laser diode, LiNbO₃ guided-wave modulators can be designed for zero-chirp or adjustable-chirp operation. Zero-chirp and negative-chirp modulators help to minimize the system degradation associated with fiber dispersion. It has found widespread use in fiber-optic communication systems, including both chirped and zero-chirp NRZ and RZ digital transmission formats. These DWDM NRZ data signals were amplified by an erbium-doped fiber amplifier (EDFA). An erbium-doped fiber amplifier (EDFA) was used to compensate for the LNM insertion loss and converted to a combined four 40 Gb/s DWDM return-to-zero (RZ) data signals by utilizing a Mach-Zehnder Modulator (MZM). DWDM systems, as RZ modulation causes a significant Eye Closure Penalty near end channels. To compensate the frequency chirp induced by the MZM for the DWDM RZ data signals a tunable dispersion-compensating module (TDCM) was employed and conventional technique using dispersion-compensating fiber (DCF) is no longer suitable due to large dispersion slope of DCF. The TDCM also can be used for compensating the chromatic dispersion of a long span of transmission fiber. The pulse widths of the DWDM RZ data signals after the MZM were around 10 ps at 40 Gb/s, which are not narrow enough for multiplexing to ultrahigh-speed OTDM signals. Before injected into the RA-MPC for adiabatic soliton pulse compression. It is important to ensure fundamental soliton power of the DWDM RZ data signals. In addition, delay blocks are also required to control the timing between the DWDM RZ data signals. To fulfill these two requirements, we constructed a DWDM power and time controller (DWDM-PTC), consisted of an arrayed waveguide grating (AWG), variable optical attenuators (VOAs) in series with tunable delay lines (TDLs), and a coupler. Arrayed waveguide gratings (AWG) are commonly used as optical (de)multiplexers in wavelength division multiplexed (DWDM) systems. These devices are capable of multiplexing a large number of wavelengths into a single optical fiber, thereby increasing the transmission capacity of optical networks considerably. The devices are based on a fundamental principle of optics that light waves of different wavelengths interfere linearly with each other. An optical attenuator is a device used to reduce the power level of an optical signal, either in free space or in an optical fiber. The basic types of optical attenuators are fixed, step-wise variable, and continuously variable. The variable optical attenuator (VOA) which is widely used in optical networks. Variable fiber Optic test attenuators generally use a variable neutral density filter. Tunable optical delaying is a valuable function in optical telecommunication networks since it enables important applications such as buffering, packet synchronisation or jitter control. The total power of the DWDM RZ signals injected into the RA-MPC was set to 9.6 dBm, which was equal to the fundamental soliton power. The RA-MPC is based on adiabatic soliton compression technique in the Raman amplifier, which contains 17 km of dispersion-shifted fiber (DSF) and a tunable fiber Raman Laser (TFRL). The second- and third-order dispersions of the DSF are 3.8 ps/nm/km and 0.059 ps/nm²/km respectively. The Raman pump signal generated by the TFRL is injected into the counter-propagating direction by using a DWDM coupler. To achieve high quality compression performance, Raman pump wavelength was optimized at 208.045 THz for all DWDM RZ data signals. The pulsewidths of the DWDM RZ data signals were compressed at each different wavelength as its peak power increases with the increase of the Raman pump power since the soliton condition is maintained in the DSF during the amplification. The compressed DWDM RZ data signals, which are temporarily shifted relative to each other by the DWDM-PTC, were coupled with a continuous wave (CW) pump at the wavelength of 192.483 THz before injected into the fiber-based XPM switch for DWDM-to-OTDM conversion. In the fiber-based XPM switch, a 0.5 km long HNLF was used for XPM process between the compressed DWDM RZ data signals and the CW pump [2]. The HNLF used has a zero dispersion wavelength of 193.165 THz, a dispersion slope of 0.032 ps/nm²/km, and a nonlinear coefficient of 12.6 W⁻¹ • km⁻¹. The total powers of the CW pump and the compressed DWDM RZ data signals into the HNLF was set at 25 dBm and 23.5 dBm, respectively. Since the DWDM RZ data signals are shifted relative to each other in the time-domain by the DWDM-PTC, no interactions occur among them during the nonlinear process. The phase modulation generated on the CW pump due to the DWDM RZ data signals was converted to intensity modulation by two 3 nm optical bandpass filters (OBPFs) positioned at a center wavelength of 192.174 THz. In this way, a 160 Gb/s

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OTDM data signal can be achieved at the output of the fiber-based XPM switch. The converted 160 Gb/s OTDM data signal was demultiplexed to 40 Gb/s base rate by using a four-wave mixing-based demultiplexing. The demultiplexed signals were then sent to a 40 Gb/s receiver for BER measurement. **III.RESULTS AND DISCUSSION**

To examine the performance of the RA-MPC, the quality of the compressed 4×40 Gb/s DWDM RZ data signals were characterized autonomously by using two 3.0 nm OBPFs after the RA-MPC for channel selection. Fig. 2(a) show optical spectra of 4×40 Gb/s DWDM RZ data signals at the output of the RA-MPC and the autocorrelation traces of output channel 2 as a function of Raman pump power (P_r). Both the optical spectra and autocorrelation traces of the compressed pulses were well fitted to sech² functions. It can be seen that the output spectra of the 4×40 Gb/s DWDM RZ data signals were increasingly broadened at the same time with the increase of the Raman pump power over the adiabatic soliton compression. The input RZ data signal at channel 2 with pulsewidth of 10.07 ps was considerably compressed to 3.02 ps, 1.66 ps, and 0.52 ps as the Raman pump power was set at 1.00 W, 1.50 W, 2.1 W, respectively. Fig. 3 shows the eye pattern of the compressed 4×40 Gb/s DWDM RZ data signals captured by a 30 GHz-bandwidth digital sampling oscilloscope at the output of RA-MPC in the case of $P_r = 2.1$ W. Although channels are on different wavelengths, they look like a 160 Gb/s OTDM data signal due to the 10 ps interleaving among channels. The channel selection was carried out by using two 3.0 nm OBPFs. Both the optical spectra and autocorrelation traces of the compressed 4×40 Gb/s DWDM RZ data signals were well fitted to sech² functions.

The measured pulse widths had full width at half maximum (FWHM) of 0.58 ps, 0.52 ps, 0.46 ps, and 0.66 ps for channel 1, 2, 3, and 4, respectively. The obtained results show that the RAMPC generates the good quality for all compressed 4×40 Gb/s DWDM RZ signals, which is essential for subsequently DWDM to OTDM conversion in the fiber-based XPM switch. Fig. 3 shows the optical spectra at the output of the HNLF, output 160 Gb/s OTDM data signal at the output of fiber-based XPM switch after filtering at 192.174 THz. The combined four 40 Gb/s DWDM RZ signals can be seen on the left-hand side. The DWDM RZ data signals modulated the phase of CW pump, leading to the broadened spectrum of the CW pump as seen on the right-hand side. The strong modulation peaks spaced 160 GHz in the spectra at the output of fiber-based XPM switch show the successful

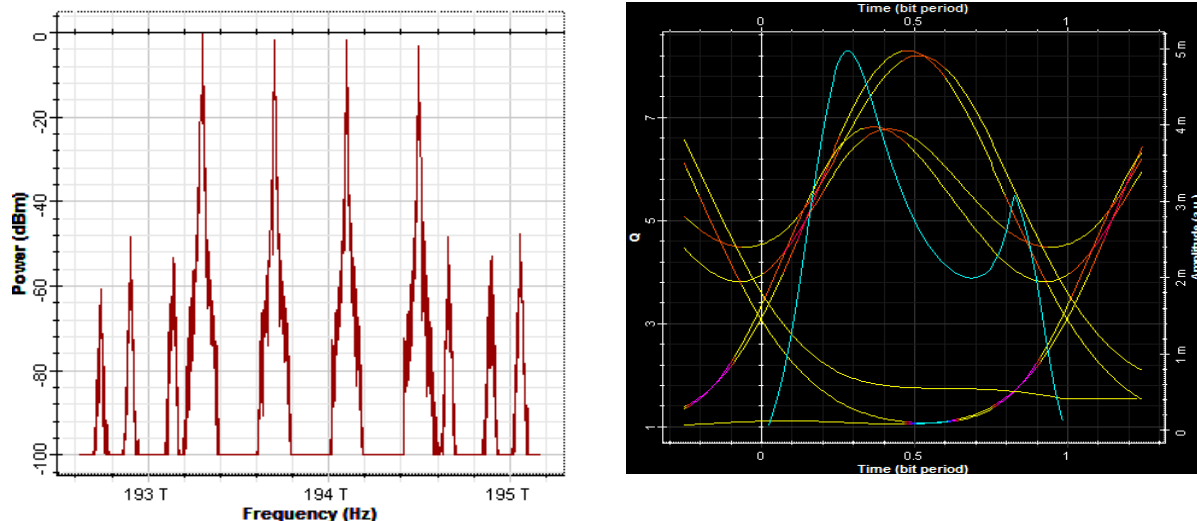


Fig. 2 (a) show optical spectra of 4×40 Gb/s DWDM RZ data signals at the output of the RA-MPC and (b) shows the eye pattern of the compressed 4×40 Gb/s DWDM RZ data.

Converting to 160 Gb/s OTDM data signal. Fig. 3 shows the output eye pattern of the 160 Gb/s OTDM data signal captured by a 30 GHz-bandwidth digital sampling oscilloscope. Clear eyeopening in Fig. 3 shows that the present systems successfully perform the conversion of 4×40 Gb/s DWDM channels to one 160 Gb/s OTDM channel. After the DWDM-to-OTDM conversion, the OTDM signal was demultiplexed and then evaluated by BER measurement for investigating the quality of the signal. We obtained the error-free operation for all channels. All channels performed almost the same and less than 1-dB power penalty at BER = 10^{-9} was achieved for all demultiplexed channels compared to the back-to-back signal. Note that the gain bandwidth of the Raman amplifier in this letter is about 12 nm.

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Therefore, 4×40 Gb/s DWDM signals with wavelength spacing of 3.2 nm have been compressed to around 0.5 ps FWHM which is capable of time multiplexing the compressed WDM channels to 4×80 Gb/s and converting to one OTDM channel with bit-rate up to 320 Gb/s. Due to the limited bandwidth of the Raman amplifier employed in this letter, the current demonstration faces a challenge to be functional for higher OTDM bit-rates over 320 Gb/s, which requires wider gain bandwidth and shorter pulse operations of the Raman amplification/compression process.

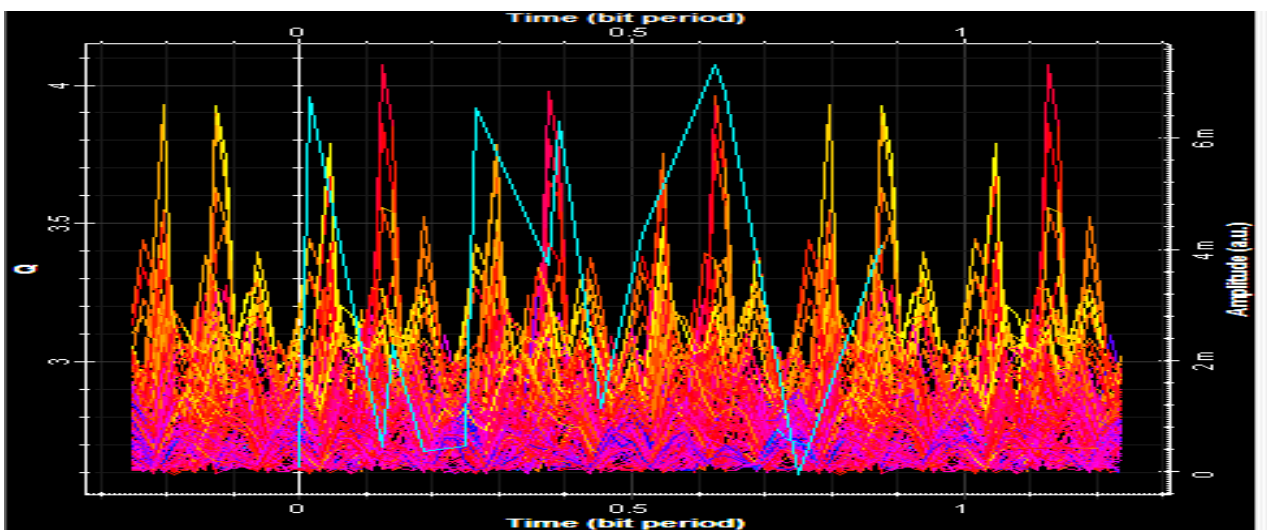


Fig .3 Output eye pattern of the 160-Gb/s OTDM data signal.

IV. CONCLUSION

I have successfully simulated a short pulse width-tunable multi-wavelength pulse generation by means of adiabatic soliton compression in a single distributed Raman amplifier. All-optical format conversion from 4×40 Gb/s DWDM channels to one 160 Gb/s OTDM channel by using the RA-MPC and fiber-based XPM switch. The pulse trains were compressed with flexibly pulsewidth-tunable range from 10 ps to less than 0.5 ps by controlling the Raman pump power. High quality compressed pulses were achieved in all operating Raman pump powers in wide channel spacing operations. In this project DWDM-to-OTDM conversion a complete interchange between WDM and OTDM can be done in flexible manner at photonic gateways of WDM/OTDM networks.

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