1700 ps/nm tunable dispersion compensation for 10 Gbit/s RZ lightwave transmission

G.-H. Lee, Z. Jiang, S. Xiao and A.M. Weiner

Programmable chromatic dispersion compensation with a virtually-imaged phased-array and spatial light modulator for 10 Gbit/s RZ data transmission (both 33% RZ and 50% RZ formats) with tuning range up to −1700 ps/nm is demonstrated.

Introduction: Tunable dispersion compensation is becoming inevitable for fibre-optic communication systems. Important applications include replacing conventional dispersion compensating fibres (DCFs) in long-haul transmissions, compensating residual dispersion after the DCF to meet the tight dispersion tolerances required in 40 Gbit/s and above based networks, and compensating thermally-induced variations in dispersion which can be as large as ±30 ps/nm [1]. Moreover, it is known from the theory that for high data rate transmission, return-to-zero (RZ) signalling formats are superior to the non-return-to-zero (NRZ) signalling formats, owing to their increased robustness to many distortions from fibre propagations [2].

Previous works on tunable dispersion compensation for RZ signal transmissions include nonlinearly-chirped fibre Bragg grating [3] and multicavity etalon [4] based tunable dispersion compensators (TDCs). However, the tuning range of these works is limited to ±250 ps/nm. Recently, we have demonstrated a TDC capable of producing a tuning range of −2040 to +850 ps/nm using a transmission setup with 10 Gbit/s positively chirped NRZ signals [5]. Here, we extend our work to demonstrate tunable chromatic dispersion compensation for 10 Gbit/s RZ signal transmissions with different pulse durations using standard SMF up to 100 km (−1700 ps/nm).

Experiments and results: The layout of our TDC, which is based on an optical pulse shaping configuration [6], is shown in Fig. 1*a*. It is similar to the setup in [7] but the curved mirror is replaced with a spatial light modulator (SLM) to provide programmability without any moving parts [5]. The optical input is fed into a virtually-imaged phased-array (VIPA) using a cylindrical focusing lens. The VIPA spatially disperses the wavelength components within the optical input, and another lens focuses spatially dispersed wavelength components at the Fourier plane. To achieve tunable chromatic dispersion compensation, we applied a quadratic phase distribution that varies with the wavelength (spatial position) [5] by using a standard two-layer, 128-pixel liquid crystal SLM at the Fourier plane [6]. The insertion loss for the TDC including circulator and polarisation controller is around 15 dB. Other design parameters used in the TDC setup include the focal length of the semi-cylindrical lens (~100 mm), the input angle into the VIPA (~2°), and the focal length of the focusing lens (~300 mm). As demonstrated in our previous 10 Gbit/s NRZ transmission experiments [5], our TDC setup is polarisation independent and can work simultaneously on different DWDM channels spaced by the free spectral range of the VIPA (here 50 GHz).

We composed an RZ signal transmission setup as shown in Fig. 1*b* to measure the TDC performance in terms of dispersion power penalty. A pulse width and wavelength tunable RZ transmitter producing 10 Gbit/s RZ signals is used as the optical source [8]. This tunable RZ transmitter includes a 10 GHz actively modelocked fibre laser and a high resolution grating based pulse shaper which is able to resolve individual spectral lines generated from the modelocked laser. This line-by-line pulse shaper functions as a wavelength and bandwidth tunable high resolution optical filter for precise spectral line-by-line control. By appropriately setting the pulse shaper, width and wavelength, tunable pulses can be achieved in which the wavelength is determined by the passband of the pulse shaper and the pulse width is determined by the number of spectral lines passing through the pulse shaper. These pulses are passed through a standard intensity modulator for on-off keying at 10 Gbit/s. This results in a pulse width tunable RZ transmitter. In the experiment, the RZ transmitter was tuned for ~1550.1 nm centre wavelength to match the TDC passband as shown in Fig. 2. The pulse duration was tuned to produce ~30 ps pulses (~33% RZ) as shown in Fig. 4*a* (also shown in the inset of Fig. 1*b*) and ~50 ps pulses (~50% RZ) as shown in Fig. 4*d*. Two EDFAs were used to compensate the optical power loss within the system link, and various lengths of fibre spools were used to generate different dispersions (20–100 km SMF with $D = +17$ ps/nm-km) to prove the tunability of TDC, and variable optical attenuators were placed after the fibre spools to fix the insertion loss within the fibre links to 26 dB in order to maintain constant power at the second optical amplifier input for different fibre lengths. An optical bandpass filter (BPF) with ~2 nm passband was used to remove optical amplifier noise and a 10 GHz photodiode was used to detect the optical signal for BER measurements.

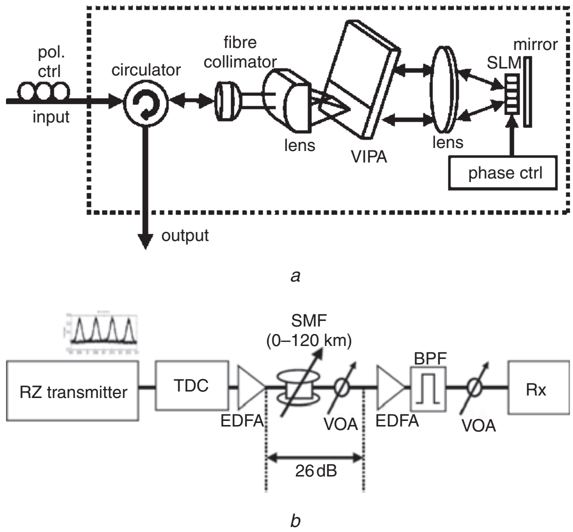

Fig. 1 *Schematic diagram for experimental setup*

a Configuration of TDC
b RZ signal transmission setup

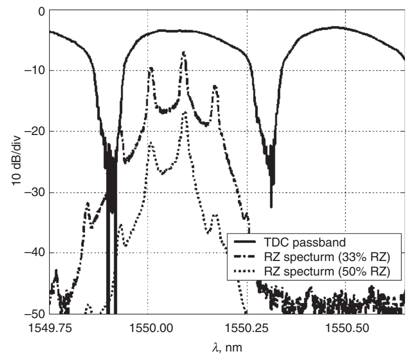

Fig. 2 *TDC transmittance and optical spectrum for optically generated RZ signal with different pulse durations*

Fig. 3*a* shows the BER for back-to-back operation without the TDC setup (B2B) and with the TDC setup but with the SLM phase set to a constant (B2B VIPA), and for 20, 30 and 40 km of SMF transmission without dispersion compensation (without TDC setup) using the RZ transmission setup with ~33 ps pulse duration in Fig. 1*b*. The dispersion power penalties for 20, 30 and 40 km of SMF transmission are 3, 6 and 10 dB, respectively. Fig. 3*b* shows the BER results when the TDC is optimised for various SMF spans up to 100 km for 33% RZ data by programming the appropriate quadratic phase function onto the SLM. The results in the Figure show error-free transmission, with the power penalty kept below 1 dB in all cases. For comparison, Fig. 3*b* also shows the BER without the TDC setup for a 20 km uncompensated SMF span that is identical to the curve in Fig. 3*a*. We also have obtained very similar (error-free) results using our TDC (same setting for given span length) for 50% RZ signal transmission over spans up to 100 km (not shown).

Fig. 4 shows typical eye diagrams (another key optical transmission performance gauge) for back-to-back and for 100 km SMF transmission both before and after chromatic dispersion compensation 33% RZ (Figs. 4*a–c*) and 50% RZ (Figs. 4*d–f*) signals. Figs. 4*a* and *d* show the back-to-back results for the 33% RZ and 50% RZ signals which were measured using a 50 GHz photodiode and a 50 GHz bandwidth sampling oscilloscope. Figs. 4*b* and *e* show the results for 100 km SMF transmission before the TDC compensation using a 10 GHz photodiode (which was used to measure the BER in Fig. 3). The eye diagrams are completely closed in both cases. Figs. 4*c* and *f* show the chromatic dispersion compensated results for 100 km SMF transmission with the TDC using a 10 GHz photodiode (which was used to measure the BER in Fig. 3). The clear eye openings in these results show the accumulated dispersions are effectively removed by the TDC, which is consistent with the BER results in Fig. 3*b*. These results clearly indicate the effectiveness of the TDC compensation for different pulse durations.

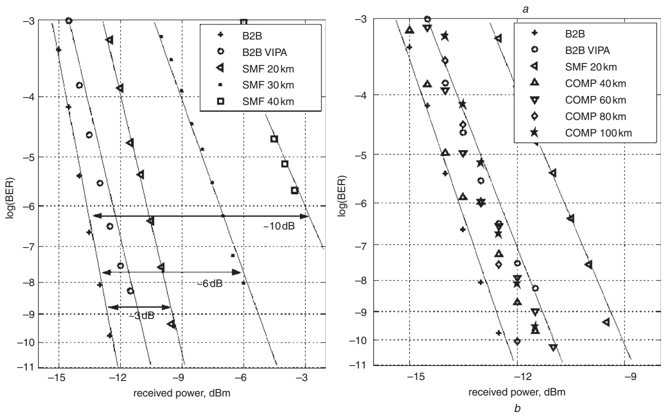

Fig. 3 *TDC measurements using 33% RZ signal source*

a BER against received power without TDC
b BER against received power after TDC compensation

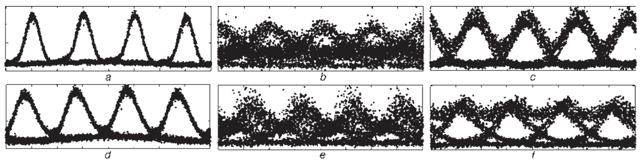

Fig. 4 *Eye diagrams (50 ps/div.)*

a For 33% RZ, back-to-back without TDC (measured by 50 GHz PD)
b For 33% RZ, 100 km SMF transmission without TDC
c For 33% RZ, 100 km SMF transmission with optimum compensation by TDC
d For 50% RZ, back-to-back without TDC (measured by 50 GHz PD)
e For 50% RZ, 100 km SMF transmission without TDC
f For 50% RZ, 100 km SMF transmission with optimum compensation by TDC

Conclusion: We have demonstrated tunable chromatic dispersion compensation up to –1700 ps/nm (100 km SMF) for 10 Gbit/s RZ data. Both the BER curves and eye diagrams remain well behaved over the full range of fibre lengths and dispersion tested, and for both 33 and 50% RZ formats. Therefore, we believe that extension to compensation of even larger amounts of dispersion should be possible.

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G.-H. Lee, Z. Jiang, S. Xiao and A.M. Weiner (*Purdue University, 465 Northwestern Ave., West Lafayette, IN 47907-2035, USA*)

E-mail: leeg@purdue.edu

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