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1.8-ps RZ-Pulse 43-Gbps Transmissions over 126-km DSF with Parametric Tunable Dispersion Compensation

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Abstract: We demonstrate 1.8-ps pulse 43 Gbps RZ-OOK transmissions over 126-km zero-DSF using a parametric tunable dispersion compensator with slope compensation. The penalty dependence on the converted wavelengths was consistent with the designed dispersion values.

OCIS codes: (060.2330) Fiber optics communications; (060.4370) Nonlinear optics, fibers

1. Introduction

Adaptive chromatic dispersion (CD) compensation is essential for future optical dynamic networks such as optical path networks. The requirements of a tunable dispersion compensator (TDC) for such networks are (1) truly colorless operation with wide and flexible seamless operating bands, (2) fast response enough for handling dynamically routed optical signals. Various kinds of TDCs have been developed, using fiber Bragg grating (FBG) [1], Etalon filters [2], planar waveguide technologies [3], and so on. However, these conventional TDCs can hardly meet the above requirements as the operating bandwidths are intrinsically limited by the fundamental tradeoff between the operating single-channel bandwidth and the amount of tunable dispersion, and so is the response time due to the mechanically or thermally tuning mechanisms.

One of the authors recently proposed a new CD compensation scheme called parametric TDC (P-TDC), that is using a tunable parametric frequency shifter and dispersive media with frequency dependent group velocity dispersion (GVD) [4], [5]. This scheme has many unique attractive features for future dynamic optical networks, such as a wide seamless operating band while providing a large tunable range, and intrinsically fast response only limited by the response speed of the tunable pump laser and tunable band pass filters used. In the past, we utilized a P-TDC for tunable CD compensation of 126 km zero-dispersion shifted fiber (DSF) and achieved almost complete restoration of 2.7 ps pulse waveform [6]. However, bit error rates have not been investigated for this particular scheme. In this paper, we evaluate 43 Gbps return-to-zero on-off-keying (RZ-OOK) transmissions over 126 km zero-DSF with the same P-TDC configuration proposed in [6].

2. P-TDC for zero-DSF transmissions

Figure 1 shows the configuration and principle of the P-TDC in the case that we adopt the phase preserving frequency shifter with spectral inversion (SI). The P-TDC input optical signal at a center frequency of ω_0 passes through the first dispersive medium denoted as D_a then the frequency is converted to ω_1 by the parametric frequency shifter with SI. For example, the frequency conversion is achieved with a tunable pump laser through the degenerate four-wave mixing (FWM) process in optical fiber [7]. Finally, the converted signal is launched into the second dispersive medium denoted as D_b. The total effective second order dispersion D_{eff} is determined as the difference of the GVD between D_a and D_b. We can tune the dispersion by changing the converted wavelength as the GVD of D_b is frequency dependent. The effective second and third order dispersion of the P-TDC output signal, D_{eff} and S_{eff} , respectively, are obtained as

$$D_{eff.} = \beta_2^{(b)}(\omega_1)L_b - \beta_2^{(a)}(\omega_0)L_a \tag{1}$$

$$S_{eff.} = \beta_3^{(a)}(\omega_0)L_a + \beta_3^{(b)}(\omega_1)L_b \tag{2}$$

where $\beta_2^{(i)}$, $\beta_3^{(i)}$ and L_i are the second and third order dispersion and the length of the fiber, respectively. The notation i denotes the dispersive medium either D_a or D_b. The detailed formulations of the P-TDC are discussed in [4].

For high-speed transmissions over DSF, the compensation of not only the GVD but also the dispersion slope is equally critical. For example, 160-Gbps transmissions require the use of the pulse width less than 2 ps, in which case as we shall see in the following only the third-order dispersion (TOD) of 126-km DSF span (16.21 ps^3) hurts significantly. Figure 2 shows the 1.8-ps transform-limited Gaussian pulse shape before and after experiencing 16.21 ps^3 TOD. The compensator has to achieve a high relative dispersion slope (RDS) of ~ 0.02 nm^{-1} for the CD compensation of the standard DSF. Therefore, the configuration of the P-TDC has to be considered such that the dispersion slope is also compensated. We chose for the first and second dispersive media of the P-TDC, the dispersion compensating fibers (DCFs) with lengths of 9.31 and 7.82 km, respectively. These DCFs are the off-the-shelf conventional DCFs that compensate both the dispersion and the slope of the standard single mode fibres (G. 652, or SMF). In the following transmission experiment, the input signal wavelength is set at 1560 nm. Table 1 shows the effective second and third order dispersion estimated from the measured fiber dispersion profiles when the converted wavelength is 1546 nm. It is confirmed from the result that both the second and third order dispersion is almost canceled at this converted wavelength. The RDS is 0.0688 nm^{-1}, more than three times as large as that of conventional DCFs having an RDS of 0.02 nm^{-1}. The wideband operation and wide-range tunable second-order dispersion of a 2.7-ps pulse train was confirmed in [6].

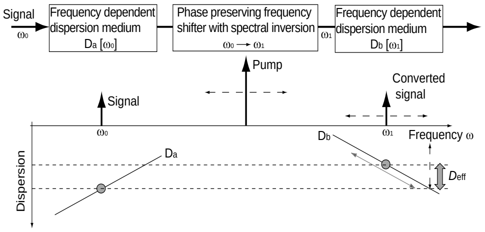

Fig. 1. Configuration and principle of P-TDC.

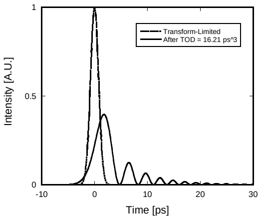

Fig. 2. Gaussian pulse shapes before and after TOD.

Table. 1. Estimation of second and third order dispersion.

	DSF	DCF-1	DCF-2
Length (km)	126 (25.2 × 5)	9.31	7.823
Loss (dB)	-28.5	-5.9	-8.9
Wavelength (nm)	1560	1560	1546
D_{eff} (ps^2)	-178.25	177.61	
S_{eff} (ps^3)	16.21	-16.25	

3. Transmission over 126 km zero-DSF with P-TDC

Figure 3 shows the experimental setup of 126-km zero-DSF transmission. The pulse source generated a 1.8-ps pulse train whose repetition rate was 43 GHz. The central wavelength was 1560 nm. The pulse train was modulated with PRBS (2^{31}-1) signals by a lithium niobate (LN) modulator. We launched the modulated 43-Gbps RZ-OOK signals into the 126-km zero-DSF, where the fiber loss was compensated by Erbium doped fiber amplifiers (EDFAs). The P-TDC compensated for the CD of the transmitted signals. As mentioned in the previous section, the P-TDC consisted of the 9.31-km DCF (DCF-1), 7.82-km DCF (DCF-2) and the wavelength converter based on the degenerate FWM. We used a CW wavelength tunable light source (TLS) for pumping the FWM in a 82-m highly nonlinear fiber (HNLF). The input pump power was about 19 dBm.

In the preliminary experiment, we launched the 1.8-ps pulse train into the transmission fiber and measured the pulse width after compensation with the pump wavelength changed. The optimal pump wavelength was found to be 1553.2 nm for the 126-km zero-DSF transmission. This result is consistent with the estimation of the P-TDC shown in Table 1. Then we measured BER characteristics of 43Gbps RZ-OOK transmission (pulse width = 1.8 ps) as the pump wavelength changed from 1551.2 to 1555.2 nm. The wavelength conversion efficiency was kept at -19 dB by adjusting the polarization states of the pump signal. Figure 4 shows the results of the BER characteristics. The BER penalty increases with the pump wavelength shifted apart from 1553.2nm. As the P-TDC has an almost linear relationship between the pump wavelength and the effective second order dispersion, the penalty is mainly attributed to the residual second order dispersion.

Figure 5 shows the relationship between the power penalty and the residual dispersion. The power penalty is defined at a BER of 10^{-3} and the reference is the BER at a pump wavelength of 1553.2 nm. The residual dispersion is estimated from the converted wavelength and the measured fiber dispersion profiles. We also plotted the simulated curve of the pulse broadening factor defined as σ/σ_0, where σ_0 is the root mean square width of the input Gaussian pulse. The slight difference between the estimated zero dispersion and the measured zero penalty point is mainly due to the frequency chirping caused by the self phase modulation (SPM). If we define the dispersion tolerance at 1-dB penalty, it is approximately 15 ps^2, which corresponds to a condition that the pulse broadening factor has to be 4 or lower. In other words, the pulse width has to be smaller than approximately one third of the bit duration of 43 Gbps. The pulse broadening factor without third order dispersion is thus well consistent with the measured power penalty.

4. Conclusion

We demonstrated the 43Gbps 1.8-ps pulse RZ-OOK transmissions over a 126-km zero-DSF with the P-TDC. The experimental results showed that the P-TDC achieved a tunable second order dispersion compensation with the dispersion slope compensation of the zero-DSF. As the signal pulse width is 1.8 ps, the tunable CD compensation at bit rates of more than 160 Gbps is expected.

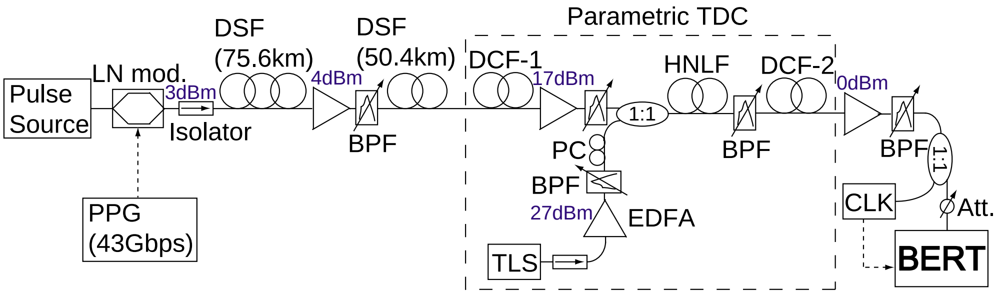

Fig. 3. Experimental setup of 43Gbps RZ-OOK transmission over 126 km zero-DSF with P-TDC.

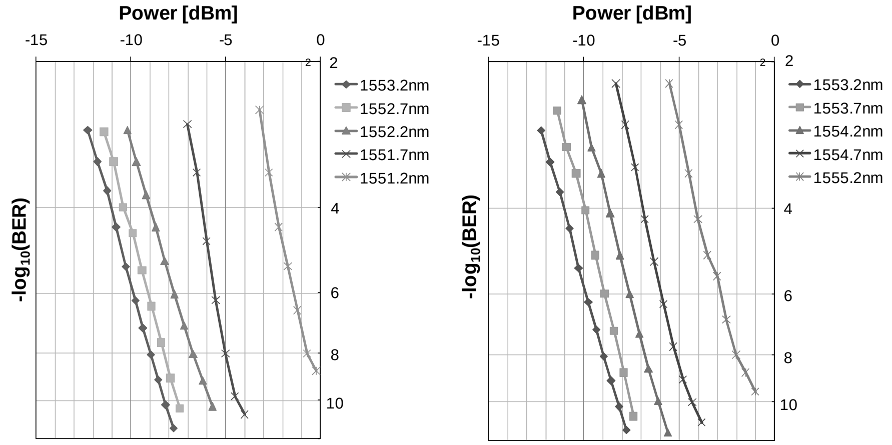

Fig. 4. BER characteristics when the pump wavelength changes from 1551.2 to 1555.2 nm.

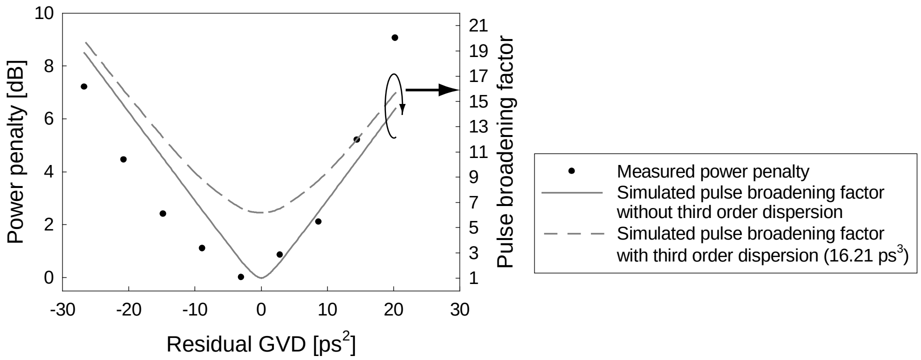

Fig. 5. Measured power penalty and simulated pulse broadening factor with or without third order dispersion.

5. Acknowledgements

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