5.94 Tb/s capacity of a multichannel tunable –700 to –1200 ps/nm dispersion compensator

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Abstract *The capacity limit of a thermally controlled fiber Bragg grating-based chromatic dispersion compensator is investigated. An equivalent quasi error-free 5.94 Tb/s capacity is demonstrated when dispersion of up to 73.8 km of SSMF is compensated.*

Introduction

The advances in Fiber Bragg Grating (FBG) technology now allow the realization of colourless slope-matched tunable dispersion compensators (TDC) that simultaneously compensate the whole C-band [1]. A recent report suggested that the idea to replace the bulky DCF by a single TDC which compensates the total CD of a transmission link independent of the WDM channel frequency could only be implemented in a 10 Gb/s system, while at 40 Gb/s a TDC could only be used as a residual CD compensator [2]. However, as Tb/s capacity transmission moves into the focus of interest it is necessary to explore the compensator capacity limit. In this experiment, a thermally-controlled FBG-based chromatic dispersion compensator which is initially designed for 10 Gb/s operation was tested. By using a CS-RZ DQPSK polarization division multiplex (PolDM) system as a testbed, a capacity of 5.94 Tb/s was successfully achieved above FEC limit with compensation for up to 73.8 km of SSMF, for the first time to our knowledge.

Tunable dispersion compensator

A tunable FBG-based dispersion compensator [1] (Fig. 1) was utilized as a 2-port device by means of a circulator.

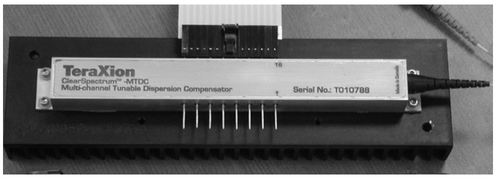

Fig. 1. Chromatic dispersion compensator

Fig. 2 shows reflectivity and mid-channel dispersions vs. wavelength when the dispersion at 194.2 THz is tuned to about –1350 ps/nm. There is a total of 51 channels with a bandwidth of at least ~35 GHz and 100 GHz spacing. A close-up of group delay vs. wavelength at various dispersion settings is shown in Fig. 3. The compensator is designed for 10 Gb/s operation but the group delay slope is constant well beyond the marked 30 GHz fit bandwidth. Tuning is possible from –700 to more than –1500 ps/nm. Total insertion loss of compensator, circulator and connectors is on the order of 5 dB. Total electrical cooling and heating power is ≤ 5 W.

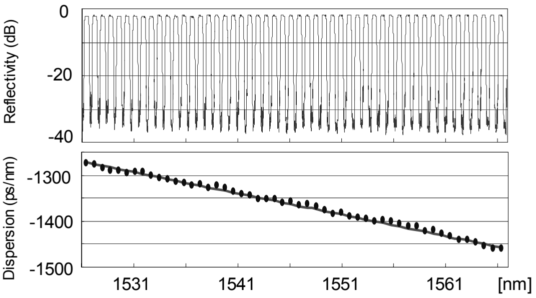

Fig. 2. Reflectivity and mid-channel dispersions vs. wavelength at –1350 ps/nm

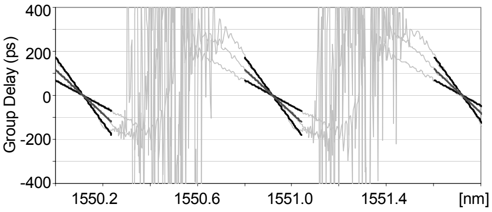

Fig. 3. Close-up figure of group delay vs. wavelength at various dispersion settings

Capacity and tunability assessment

A 40 channel, 2x2x40 Gb/s DQPSK PolDM system [3] was used to evaluate the compensator performance. PolDM was optional, and the raw aggregate data rate was therefore either 3.2 or 6.4 Tbit/s (Fig. 4). The compensator was placed behind the first optical preamplifier. Several distances of SSMF ranging from 41.5 km to 73.8 km were used to test the compensator tunability. The 40 installed WDM channels were sufficient to test also the slope compensation of the device. Dispersion and its slope are tuned simultaneously by a thermal gradient to match SSMF lengths.

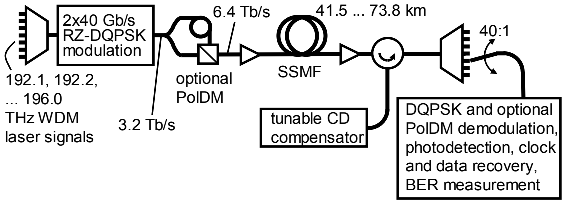

Fig. 4. 3.2 Tb/s RZ-DQPSK system, or 6.4 Tb/s using optional polarization division multiplex (PolDM)

Standard DQPSK signals applied with different polarizations allowed to determine the compensator PMD. It was ~5 ps for this particular device, while below 1 ps is the standard value for other devices of the same type.

Fig. 5 shows the bandwidth limitation of the compensator. The passband is inversely propotional to the compensation value, which limits performance at high dispersion settings. This can be seen in Fig. 6 where BER vs. optical power is given for various distances, without and with PolDM. A part of the degradation (for PolDM) in the presence of fiber is also caused by fiber nonlinearities.

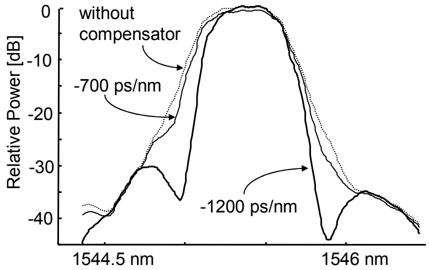

Fig. 5. Dispersion setting dependent narrowing of optical spectrum of a WDM channel by compensator

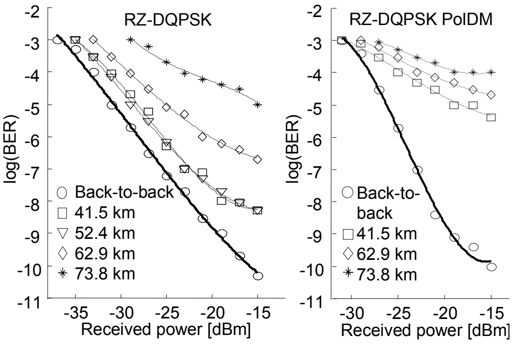

Fig. 6. Preamplified receiver sensitivity of one DQPSK WDM channel, without and with PolDM

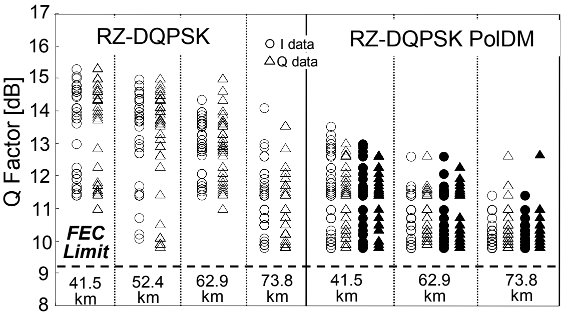

Fig. 7. Q factors for various SSMF distances. Hollow and filled markers differentiate the two polarizations in RZ-DQPSK PolDM.

Fig. 7 shows measured Q factors for both modulation formats and various SSMF distances. Associated nominal compensator settings ranged between –700 (41.5 km) and about –1200 ps/nm (73.8 km). Each column corresponds to one quadrature and contains 40 Q factor entries, for the 40 WDM signals. DQPSK has 2 quadratures (I&Q), and PolDM doubles this number by the presence of 2 polarizations. Careful interferometer adjustment might increase some of the lowest Q factors, especially at low distances, but this was not undertaken in order to expedite measurements. This explains why the lowest Q factors are almost identical at various distances and formats; our goal was just to beat the FEC limit. FEC with the indicated 9.2 dB threshold requires a 7% overhead [4]. The transmitted raw capacities of 3.2 and 6.4 Tb/s for DQPSK without and with PolDM, all above the FEC limit, therefore correspond to quasi error-free net capacities of 2.97 and 5.94 Tb/s, respectively.

At each SSMF distance, the compensator setting was identical for all 40 WDM channels, which indicates that the dispersion slope compensation is satisfactory. This can also be seen from the eye diagrams, taken at the lowest (192.1 THZ) and highest (196.0 THz) WDM channel frequencies (Fig. 8; read caption). At longer distance the eye diagram quality degrades due to the limited compensator bandwidth. The use of a TDC with larger bandwidth would improve the results presented in Fig 8.

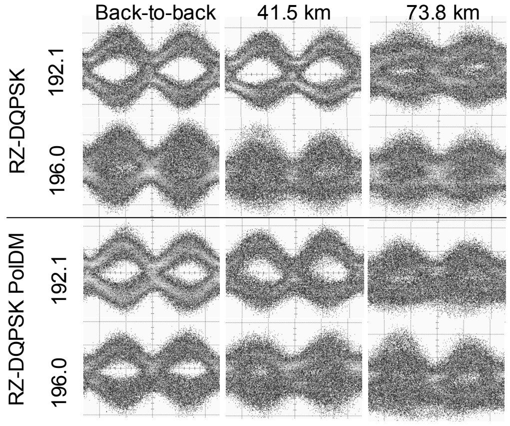

Fig. 8. Eye diagrams for both modulation format. Clock-and-data recovery contains an electrical highpass filter which could not be used during eye diagram recording. This explains why some of the eye diagrams seem to be more closed than permissible

Conclusions

A tunable dispersion compensator initially designed for 10 Gb/s operation was operated between –700 and –1200 ps/nm. Using 40 40Gbaud WDM channels, RZ-DQPSK modulation and optional polarization division multiplex, quasi error-free total net capacities of 2.97 and 5.94 Tb/s were demonstrated. This is, to our knowledge, the largest capacity demonstrated for a tunable dispersion compensator.

References

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