Adaptive 700...1350 ps/nm chromatic dispersion compensation in 1.6 Tbit/s (40×40 Gbit/s) DPSK and ASK transmission experiments over 44...81 km of SSMF

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Abstract

Full-band 1.6-Tb/s adaptive chromatic dispersion compensation is demonstrated for the first time. A multichannel tunable dispersion compensator is automatically controlled by arrival time detection on one out of 40 WDM channels transmitted.

1 Introduction

The upgrading of existing standard SMF (SSMF) links to 40 Gbit/s per WDM channel presently requires measurement of dispersion and its subsequent compensation by tailored lengths of dispersion-compensating fiber, see e.g. [1]. To avoid this costly process and to improve network reconfigurability, operators prefer to have adaptive dispersion compensators. For cost reasons there is strong interest in a periodic frequency response and multichannel tunable dispersion compensation [2-6]. Here we report, for the first time to our knowledge, on full band chromatic dispersion compensation at 40 Gb/s per WDM channel, using one multichannel, grating-based, adaptive dispersion compensator that was initially designed for 10 Gb/s system.

2 Experimental Setup

Fig. 1 shows the 40×40 Gbit/s transmission setup, similar to [7]. 2^{7-1} PRBS data at 40 Gb/s is obtained from an experimental 16:1 multiplexer that combines 16 2.5 Gb/s sub-channels mutually delayed by multiples of 8 bits. The multiplexer introduces ISI and does not allow error-free transmission of longer PRBS, not even electrically back-to-back. Data is impressed in a dual-drive MZ modulator onto 40 WDM channels (192.1 ... 196.0 THz) with 100 GHz channel spacing. The modulation format is either ASK, with a chirp of –0.22 for experimental convenience, or zero-chirp DPSK. Another MZ modulator driven at 20 GHz carves 67% CSRZ pulses for ASK modulation. Transmitted power is 2 dBm per channel.

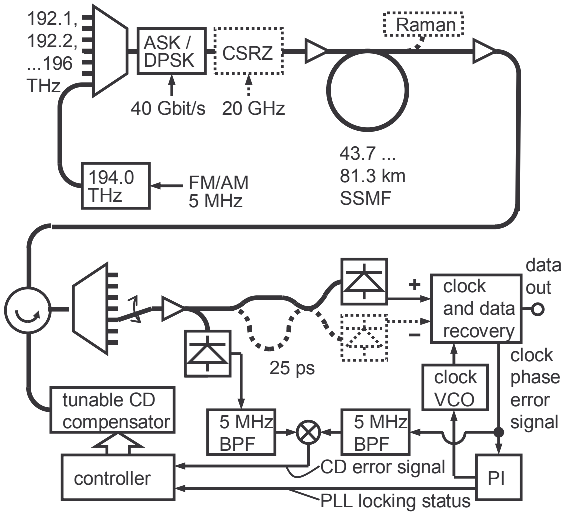

Fig. 1: 40×40 Gb/s transmission setup with adaptive multichannel chromatic dispersion compensation.

The signals are transmitted over various lengths of SSMF to the receiver. A fiber Bragg grating based dispersion compensator is inserted by means of a circulator. Dispersion and its slope are tuned simultaneously by a thermal gradient to match SSMF lengths between 44 and 81.3 km. Fig. 2 shows reflectivity, group delay and mid-channel dispersions vs. wavelength when the dispersion at 194 THz is tuned to about –1350 ps/nm. There is a total of 51 100GHz-spaced channels with a bandwidth of at least ~35 GHz. 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. While PMD is usually as low as 2 ps this particular device had a PMD of 5 ps.

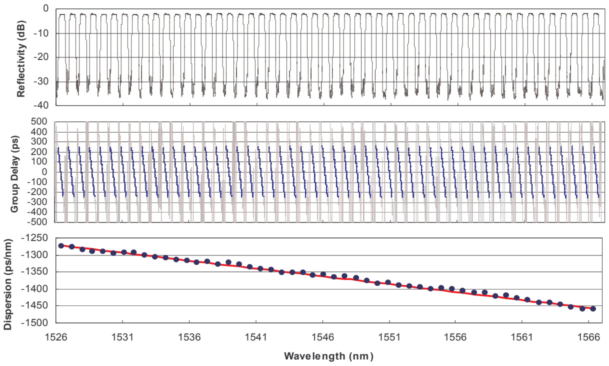

Fig. 2: Reflectivity, group delay and mid-channel dispersions vs. wavelength at –1350 ps/nm midband dispersion.

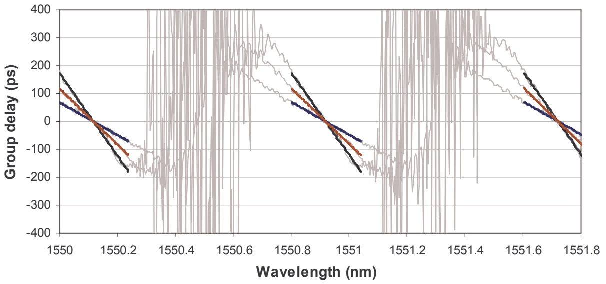

Fig. 3: A close-up figure of group delay vs. wavelength at various dispersion settings.

The dispersion-compensated signals pass a WDM DEMUX, a 40:1 fiber switch and subsequent EDFAs as well as a 2 nm wide tunable bandpass filter (not shown) for removal of broadband noise. The amplifier gain is stabilized for constant receiver photocurrent. For ASK the signal was directly detected by a photodetector. For DPSK a temperature-stabilized all-fiber interferometer with a 25 ps delay was inserted, and two differentially connected photodiodes were used. The electrical signal produced by one of the photodiodes was tapped and its RF power was monitored in a Schottky diode power detector (not shown). A lock-in scheme acts on a piezo fiber stretcher in the interferometer and maximizes the RF power. A standard clock-and-data recovery (CDR) with 20 GHz clock signal was used. BER performance was almost identical in even and odd data subchannels.

A small sinusoidal 5 MHz pump current modulation was applied to the 194.0 THz transmitter laser. It caused a ~400 MHz peak-to-peak frequency modulation and a ~2% power modulation. A small portion of the received optical signal was detected in a low-frequency receiver.

A bandpass filter recovers the 5 MHz amplitude modulation as a reference signal. In the presence of dispersion the FM causes an arrival time modulation, typically in the femtosecond range. It was sensed by the clock phase error detector of the CDR and amplified by the proportional-integral (PI) controller of the clock PLL. After amplification and bandpass filtering, the arrival time detection signal is multiplied with the reference signal in a signal processor. The multiplier output signal is proportional to the experienced residual dispersion, including its sign [8].

For initial signal acquisition, the chromatic dispersion setting is swept and the locking of the clock PLL is monitored. Then the dispersion is tuned into the center of the PLL locking range. Subsequently the dispersion is held, and tracked if necessary, by integrating the dispersion error signal. The control time constant of the compensator is 10 s, a value which could be improved by using a better thermal control. In a commercial system the signals of the 194.0 THz receiver would be utilized to control the compensator, and those of another (near) mid-band channel, also equipped with laser pump current modulation, would constitute a reserve in case of a channel failure. Here we activate control when the 194.0 THz channel is received, and freeze the integrator output signal (= dispersion control signal) when other channels are selected.

3 Transmission results

After transmission and dispersion compensation the WDM signals are decorrelated. For instance, a 1350 ps/nm fiber dispersion introduces a group delay of 1080 ps between neighbor WDM channels. Due to its sampled nature and short physical length, the compensator removes only the intra- but not the inter-channel group delay spread. Therefore the setup can be considered as completely realistic even though all WDM channels are modulated together.

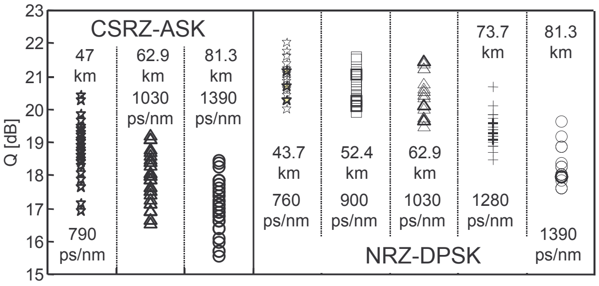

Fig. 4: *Q* factors for CSRZ-ASK and NRZ-DPSK at various transmission distances, in each case for 40 WDM channels.

Fig. 4 shows measured *Q* factors for both modulation formats and various SSMF distances. Associated nominal compensator settings ranged between –700 (43.7 km) and –1350 ps/nm (81.3 km). Later it was found that, due a temperature setting error, the true values were –760 and –1390 ps/nm, respectively. Each column contains 40 symbols, one for each WDM channel. CSRZ-ASK is a weaker modulation format. The worst-case *Q* factors range from 16.9 dB for 47 km to 15.6 dB (BER = 10^{-9}) for 81.3 km of SSMF. Due to the negative chirp, the shortest possible distance was 47 km. The worst case Q factors for zero-chirp NRZ-DPSK range from ≥ 20 dB for 43.7 km to 17.4 dB for 81.3 km of SSMF.

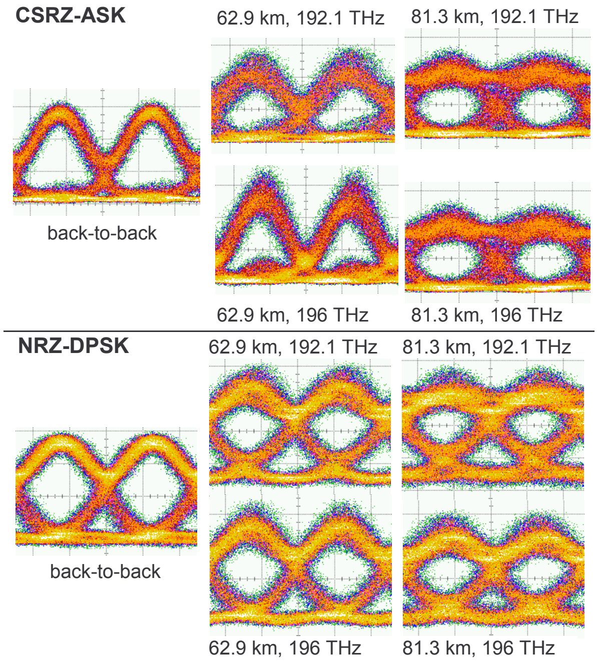

Fig. 5: Eye diagrams at lowest and highest channel frequency depending on modulation format and distance.

The dispersion slope compensation is also satisfactory. This is seen from a number of eye diagrams, taken at the lowest and highest channel frequencies (Fig. 5). The bandwidth limitation by the compensator increases with the compensated fiber length.

Duobinary modulation was not available in this experiment. However, our results suggest that the dispersion compensator would be very well suited for a transmission system with duobinary modulation. Also, since compensator bandwidth scales inversely with dispersion while the Q factor drops gradually with increasing dispersion, we expect performance beyond the FEC limit to be possible at 43 Gb/s.

4 Conclusions

This 1.6 Tb/s, 43.7...81.3 km SSMF transmission experiment shows that chromatic dispersion and its slope can be compensated in the fully populated C band at 40 Gb/s per WDM channel, using tunable devices that were initially designed for 10 Gb/s operation. The compact FBG, thermally tuned from –760 to –1390 ps/nm, and the arrival time detection scheme are suitable for a low-cost dispersion compensation solution in SSMF-based high-capacity metro systems. Similar designs could also be used for tracking and compensation of temperature-induced dispersion fluctuations in long haul systems.

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