Fully automatic, tunable chromatic dispersion compensation at 40 Gbit/s in ASK and DPSK, NRZ and CSRZ, 263 km transmission experiments

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Abstract: *Residual chromatic dispersion of a fiber link with up to 263 km length is automatically compensated for NRZ-ASK, CSRZ-ASK, NRZ-DPSK and CSRZ-DPSK modulation formats at 40 Gbit/s, using synchronous arrival time detection and a thermally tunable, –300 to –700 ps/nm dispersion compensator.*

Introduction

Tunable chromatic dispersion (CD) compensation is needed in long haul and dynamically routed transmission links, especially at 40 Gbit/s. Various integrated optical dispersion compensators [1-5] have been demonstrated but a fiber Bragg grating exhibits the largest dispersion range, with an associated large tunability. Among many CD detection schemes, synchronous arrival time detection with a sensitivity of at least 200 attoseconds [6] is the most promising option because the scheme has an extremely low incremental cost, provides the sign of CD and is usable for various modulation formats [7]. The tolerance to residual CD with respect to in-line CD compensation ratio for various modulation formats including NRZ-ASK, CSRZ-ASK, NRZ-DPSK and CSRZ-DPSK was evaluated numerically in [8] at 43 Gbit/s. To our knowledge, we report here for the first time on automatic chromatic dispersion compensation for all these modulation formats in a 40 Gbit/s transmission experiment, using a thermally tunable dispersion compensator.

Transmission setup

Fig. 1 shows our transmission setup. A 192.5 THz (1557.366 nm) DFB laser is modulated with a 5 MHz sinusoidal source to provide 1.8% rms power modulation and 336 MHz rms frequency modulation. A 40 Gbit/s 2^7–1 PRBS obtained from an Infineon 16:1 MUX is impressed as DPSK or ASK on the optical carrier using a Triquint dual drive modulator. Another Triquint modulator driven at 20 GHz generates CSRZ pulses when required. This signal is transmitted over 3 fiber spans with a total length of 263 km. The spans were mixed from 170 km of SSMF, 60 km of NZDSF, and 33 km of DSF. DCF with a total dispersion of –2713 ps/nm was inserted between first and second stages of the two inline EDFA's. At the receive end there is an optical preamplifier followed by a 40 channel, flat top WDM DEMUX (Optun). Our FBG-based tunable dispersion compensator is inserted just before the receiver using a 3-port optical circulator. It is followed by an optical tap and a low frequency power monitor photodiode to recover the power modulation which is used as a reference signal for arrival time detection. DPSK signals are decoded using a Mach-Zehnder interferometer with a 100 ps delay. Both interferometer outputs are connected to high-speed photodiodes, which in turn are connected to the differential inputs of an Infineon clock and data recovery circuit with 1:16 DEMUX. BERs in even and odd DEMUX channels are about the same. For ASK operation, the interferometer and one photodiode are left out.

For arrival time detection, the band pass filter that follows the low frequency photodiode detects the parasitic 5 MHz AM to provide a reference for 5 MHz lock-in detection of the clock phase error signal in the CDR circuits. In the presence of CD, the FM causes small arrival time modulation, which is indicated by the clock phase detector. Due to a lock-in scheme, the CD error signal is directly proportional to the residual CD including its sign. The noise of the 5 MHz component of arrival time modulation is only $2 \cdot 10^{-16}$ s for DPSK, and 10^{-16} s for ASK. In order to keep the CD readout independent of optical input power fluctuations, the detected photocurrent is stabilized by a feedback loop that controls the pump current of the last EDFA.

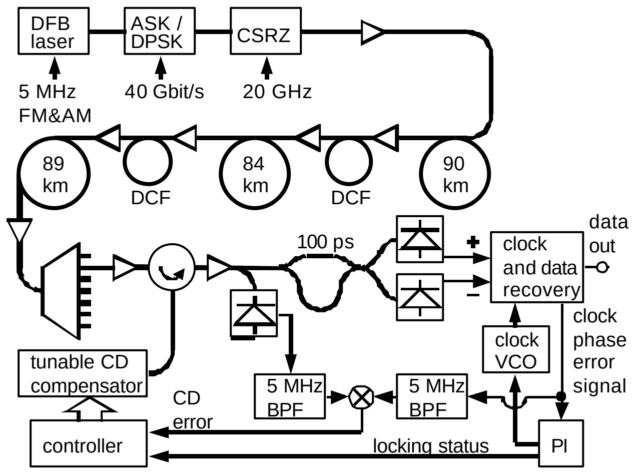

Fig. 1: CDC Setup for 40 Gbit/s ASK and DPSK transmission

Experiment

Fig. 2 shows OSNRs in dB/0.1nm, which all result in BER = 10^{-9}. They are given as a function of a manually adjusted compensator CD with a 258 km fiber link in place. The optimum CD value for NRZ-ASK differs from that for the other formats, maybe because the ASK modulator drive voltage is too large (see also Fig. 4). Automatic CD compensation is carried out by a DSP in the following way: at first, the dispersion compensator is thermally scanned through its –300 ps/nm to –700 ps/nm CD tuning range. Then it is set into the middle of that region where the clock recovery PLL locks successfully. Finally, an integrator controls the value of the CD. The integrator input is driven by the CD error signal. Integration stalls when the CD error signal vanishes and indicates zero residual CD. Temporal variations of CD are automatically tracked. The electrical heating/cooling power required to control and tune the compensator is 10 W. A thermal scan takes 10 minutes, and the control time constant is about 45 s, but control speed was not optimized.

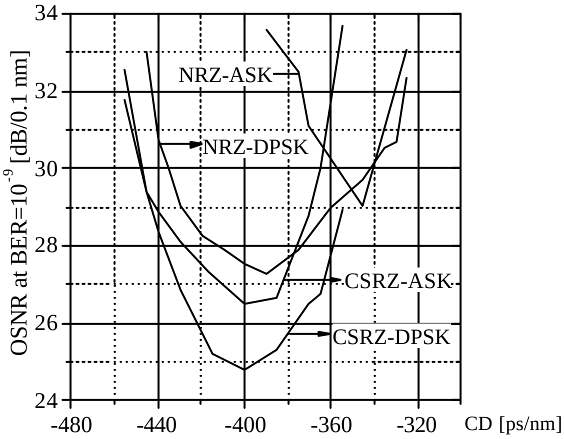

Fig. 2: OSNR needed for BER = 10^{-9} versus compensator CD

The back-to-back *Q* values for NRZ-ASK, CSRZ-ASK, NRZ-DPSK and CSRZ-DPSK are 24.6, 26.6, 25.8 and 29.5 dB, respectively. The corresponding back-to-back receiver sensitivities of –25.7, –27.3, –26.8, and –32.1 dBm are equivalent to OSNRs of 30.1, 27.7, 29.6, and 23.8 dB/0.1nm, respectively. Fig. 3 shows BER vs. OSNR. With the 263 km fiber link, the *Q* factors are reduced to 17.3, 19.6, 19.1 and 20.4 dB, respectively, and they stay essentially unchanged when the tunable dispersion compensator is operational. 1 h of error-free operation was verified in each case. In order to test other compensator CDs, either 5 km or 10 km of SSMF with a –342 ps/nm piece of DCF was taken out from the link. Compensator control was always successful, and error-free transmission was possible. Corresponding BER data (258 km, 253 km) is also plotted in Fig. 3. The combined penalties of transmission and CD compensator were measured to be between –1.2 dB (an improvement) and +1.2 dB. Fig. 4 shows received eye diagrams for all modulation formats.

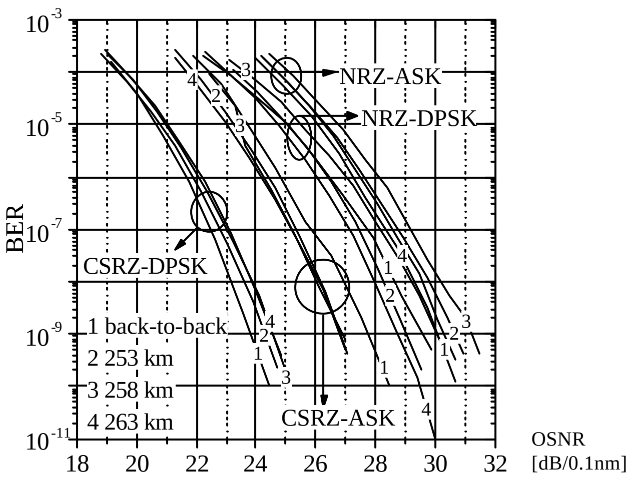

Fig. 3: BER versus OSNR. The OSNR is varied by an attenuator.

Discussion

In [9], CD has been compensated at 43 Gbit/s, but only for CSRZ-ASK. When that CD compensator was operational, the *Q* factors were about 12.5 dB, which was very close to the FEC limit. On the contrary, our *Q* factors are > 17 dB which corresponds to (almost) error free transmission with a BER < 10^{-12}. Our robust synchronous arrival time detection scheme operates with various modulation formats and is able to automatically adjust the tunable CD compensator. CSRZ-DSPK outperforms the other modulation formats in receiver sensitivity, which recommends it for long and ultra-long haul optical transmission.

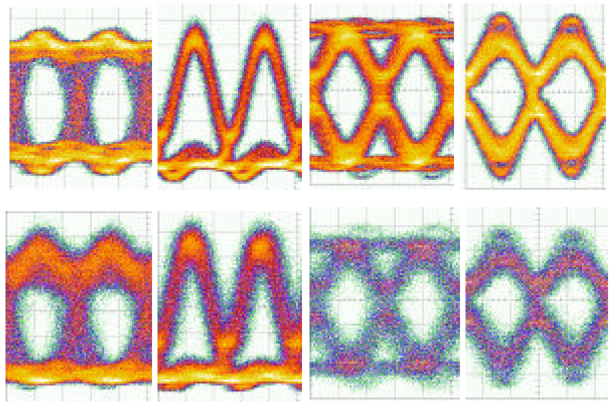

Fig. 4: 40Gbit/s eye diagrams back-to-back (top) and after 263 km transmission (bottom), for NRZ-ASK, CSRZ-ASK, NRZ-DPSK, and CSRZ-DPSK (from left to right)

Conclusion

We have compensated residual chromatic dispersion in a 263 km fiber link at 40 Gbit/s for the modulation formats NRZ-ASK, CSRZ-ASK, NRZ-DPSK, and CSRZ-DPSK. A low-cost synchronous arrival time detection scheme measured residual CD, which was in turn eliminated by automatic control of a –300 ps/nm to –700 ps/nm thermally tunable dispersion compensator. The total measured penalty of transmission and CD compensation was –1.2 dB ... +1.2 dB, for various link lengths and compensator CDs.

References

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