SIGNED ONLINE CHROMATIC DISPERSION DETECTION AT 40Gb/s WITH A SUB-ps/nm DYNAMIC ACCURACY

David Sandel, Vitali Mirvoda, Frank Wüst, Reinhold Noé
Univ. Paderborn, FB 14/850, Warburger Str. 100, 33098 Paderborn, Germany; noe@upb.de
Stephan Hinz
Siemens AG, ICN ON RD AT 3, Hofmannstr. 51, 81359 München, Germany

Abstract *A DFB TX laser is amplitude-modulated by 1.2%rms. In the presence of dispersion, associated FM modulates signal arrival time, which is measured with sub-fs error by lock-in detection of oscillator control voltage in RX clock recovery.*

Introduction

Automatic chromatic dispersion (CD) compensators are required in many 40Gb/s systems: Firstly, the operators prefer easy-to-install systems without need to taylor DCF lengths to each installed SSMF link. Secondly, in ultra-long haul systems CD depends on temperature. Thirdly, routing or protection switching in transparent networks with almost-compensated fibers may require an adaptive CD compensator. For easy control of a CD compensator residual CD, including its sign, should be measured in the receiver.

Examples of reported online CD estimation schemes include threshold scanning /1/ and clock level /2,3/ or in-band subcarrier /4/ monitoring. Most techniques employed so far do not indicate the sign of CD, require extra high-frequency electronics and/or are not flexible with respect to the modulation format (NRZ, RZ).

In the context of PMD detection, variations of the signal arrival time caused by an 84fs differential group delay have been detected by analyzing excursions of the clock recovery control signal /5/.

Here we frequency-modulate the optical signal to generate arrival time modulations in the presence of CD, which are then analyzed.

40Gbit/s data transmission setup

Fig. 1 details the setup. 40Gb/s data is 16:1-multiplexed from 2.5Gb/s with mutual delays of 8 bits. This just reproduces a 2^7-1 PRBS at 40Gb/s, whereas a 2^{23}-1 PRBS at 2.5Gb/s becomes a more complicated bit sequence at 40Gb/s. A small pump current modulation of the DFB laser at 5MHz results in a 1.2%(rms) amplitude modulation and in a frequency modulation with 224MHz(rms) deviation. The data signal arrives at the receiver after a delay that is proportional to CD times instantaneous frequency. Even a large CD of, say, 200ps/nm modulates the group delay by just 360fs(rms).

In the receiver there is a clock and data recovery with a clock phase detector inside the decision circuitry. Our clock phase detector correlates the decision circuit output signal with the output signal of another decision circuit that is clocked 1/2 bit period earlier, and subtracts an offset from the correlation result.

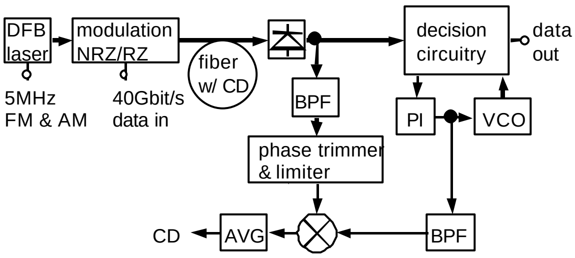

Fig 1: Experimental setup for chromatic dispersion detection

This asymmetric circuit is quite susceptible to patterning, unlike the usual symmetric circuit where another correlation is performed with the output signal of a decision circuit that is clocked 1/2 bit period later. Results will therefore be given both for a 2^7-1 PRBS as the best possible case, and a 2^{23}-1 PRBS as a conservative bound of the achievable sensitivity, given the large avoidable patterning in the clock phase detector.

The clock phase error signal is fed to a PI controller. Its output signal controls the voltage-controlled oscillator (VCO). Since the clock phase is locked to the clock information present in the data signal the integrator output signal ideally is a measure of the differentiated data signal arrival time. A sinusoidal signal is expected. For high modulation frequencies, which can be tolerated here since the arrival time modulation is very small, this signal directly reflects the arrival time. Its amplitude and sign depend on the CD. For optimum sensitivity it is useful to process the arrival time signal by synchronous (= lock-in) detection to obtain the CD value.

The necessary timing reference is conveniently obtained by detecting the parasitic amplitude modulation. Alternatively, the modulation frequency could be derived from a SONET or FEC frame period both at the transmitter and the receiver.

Parasitic AM is contained in a low-frequency copy of the detected photocurrent. Just like the differentiated arrival time it is bandpass-filtered (BPF). After being amplitude-limited it serves as a reference, with a phase that is adjusted for best sensitivity. The arrival time signal is synchronously detected and averaged. While Fig. 1 explains the principle, signals were in reality processed digitally, and an extra low-frequency photodiode was employed to detect the AM.

Chromatic dispersion detection results

40Gbit/s data was transmitted all the time, with zero bit errors as long as there were open eyes, and with no significant degradation introduced by the laser modulation. Both NRZ and CS-RZ modulation were tested. Actual CD values of fibers under test were measured separately using a tunable laser and an oscilloscope triggered from the TX side. Fig. 2 shows measured CD (a.u.) vs. actual CD in the range of -30ps/nm (33km of DSF) to +170ps/nm (11km of SSMF) for a 2^{23}-1 PRBS. Some eye diagrams are also shown.

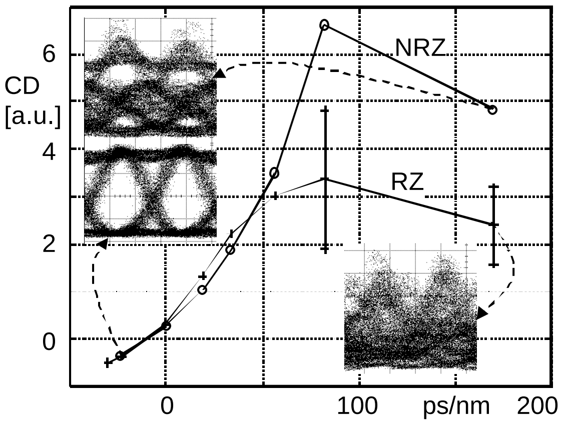

Fig 2: Measured CD (a.u.) vs. actual CD.

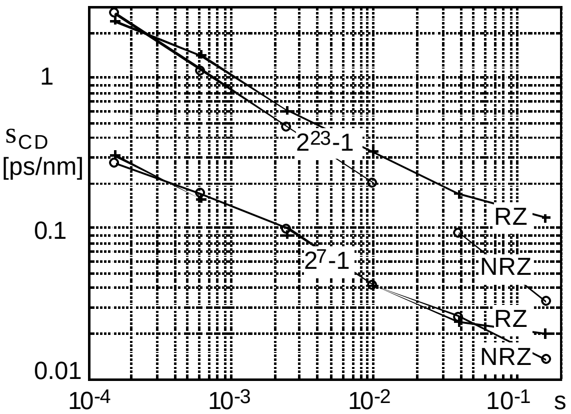

Fig 3: Standard deviation of measured CD vs. measurement interval, at zero actual dispersion.

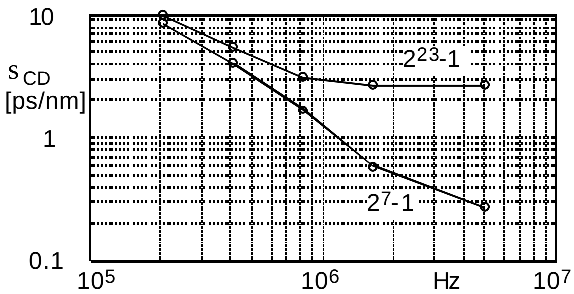

Fig 4: Standard deviation of measured CD vs. modulation frequency for NRZ, measured in 154ms.

An offset of ~10ps/nm was observed but this is not believed to be critical. The measurement interval was 154µs in each case. For a 2^7-1 PRBS readouts were similar. At 84ps/nm (for RZ) and at 170ps/nm the eye diagram was closed so much that many decisions went wrong. This decreased the CD readout and resulted in fluctuations (given by error bars for RZ). Nevertheless the sign of measured CD was indicated correctly. CD compensation could therefore be readily accomplished if a compensator with adjustable DGD were connected to the measured CD signal via a simple integrator.

The standard deviations, expressed as dispersions, are shown as a function of averaging time in Fig. 3. While this refers to zero actual CD, accuracy is not much worse at other CD values as long as there are few bit errors. If the time constant of a CD compensating scheme is at least 1ms its residual CD error will have a standard deviation in the sub-ps/nm range, which can be considered as sufficient. Since CD changes slowly the compensation system could as well be designed to control much more slowly, thereby increasing accuracy. E.g., for a measurement interval of 157ms the standard deviation for NRZ 2^{23}-1 PRBS equals 33fs/nm. This corresponds to a 60-attosecond (rms) error of the averaged 5MHz spectral component of the arrival time. This sensitivity is owed to a good VCO frequency stability and synchronous detection of the arrival time variations.

For NRZ and zero actual CD, Fig. 4 shows standard deviations in 154µs measurement intervals as a function of modulation frequency. Although the laser FM response increased below 1MHz the sensitivity was best at 5MHz where VCO phase noise is least disturbing.

It is reminded that a symmetric clock phase detector would probably perform better for 2^{23}-1 PRBS than the asymmetric one used in this experiment.

Conclusions

This chromatic dispersion detection scheme is extremely cheap to implement, features superior sensitivity, is fast enough, introduces hardly any transmission penalty, tolerates both NRZ and RZ, and provides also the sign of CD. It is ideally suited for adaptive control of an optical chromatic dispersion compensator using a simple integral controller.

References

1 K. Yonenaga et al. Electron. Lett. 27 (2001), pp. 187-189

2 A. Sano et al. ECOC 1996, Oslo, pp. 2.207-2.210

3 A.B. Sahin et al. ECOC2001, Amsterdam, pp. 446-447

4 M.N. Petersen et al. OFC 2001, WH4

5 R. Noé et al. IEEE JLT 20 (2002), pp. 229-235