PRACTICAL 40GBIT/S CSRZ-DPSK TRANSMISSION SYSTEM WITH SIGNED ONLINE CHROMATIC DISPERSION DETECTION

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Abstract *A signed online chromatic dispersion measurement scheme, a 4-bit interferometer delay which allows differential encoding at 10Gbit/s, an active interferometer phase stabilization and a standard clock-and-data recovery circuit are used in this 40Gbit/s CSRZ-DPSK system.*

Introduction

RZ-DPSK is a high-performance optical transmission scheme. A number of experiments have been reported [1-5].

However, in order to recover the clock from a 40Gbit/s DPSK signal researchers so far have needed to provide an additional 40GHz optical receiver [1,2,5]. This is undesirable for cost reasons. Another practical problem is the recursive differential encoding at 40Gbit/s because realizable feedback delays exceed 25ps. A solution is possible as described in [6], but a fair amount of additional electronics with a high power consumption is required. Finally, the interferometer phase difference must be stabilized.

Here we solve these problems and show that an extremely simple, signed online chromatic dispersion detection scheme [7] is compatible with DPSK.

Differential encoding and decoding

For a data symbol d to be transmitted, differential encoding is usually performed as $g_i = g_{i-1} \oplus d_i$ where the index identifies consecutive bits at 40Gbit/s. The encoded symbol g is transmitted in a bipolar fashion as the optical field polarity. The received symbol is differentially decoded in an interferometer having a 1-bit delay. When written with binary variables the result is $h_i = g_i \oplus g_{i-1} = d_i$, just as desired.

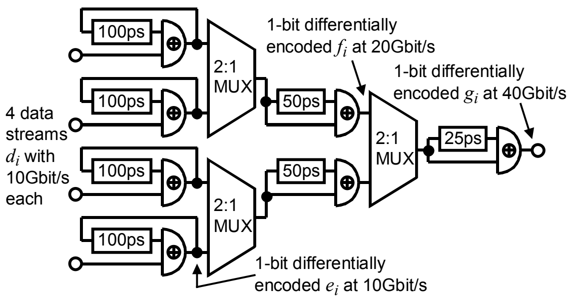

Fig. 1: Regular 40Gbit/s differential encoding scheme

We propose here a new, fully regular encoding scheme (Fig. 1). Differential encoding $e_i = e_{i-4} \oplus d_i$ takes place only at 10Gbit/s in 4 separate, parallel circuits. Then the signals are 4:2 MUXed to 20Gbit/s. Here they are modulo-2-added in 2 parallel circuits according to $f_i = e_i \oplus e_{i-2}$. After the 2:1 MUX to 40Gbit/s a similar, serial non-recursive operation occurs, $g_i = f_i \oplus f_{i-1}$. It is easy to show that the 1-bit differential decoding $h_i = g_i \oplus g_{i-1}$ results again in $h_i = d_i$. Simplifications are possible if recursive differential encoding is possible at 20Gbit/s.

Even at 10Gbit/s the DPSK laser linewidth requirements are easily fulfilled, which allows to simplify matters. Differential encoding $e_i = e_{i-4} \oplus d_i$ takes place at 10Gbit/s. The interferometer delay is chosen equal to 4 bit durations, with the result $h_i = e_i \oplus e_{i-4} = d_i$. This scheme is used hereafter.

Transmission setup

The 40Gbit/s RZ-DPSK transmitter (Fig. 2) employs a 16:1 MUX (Infineon) which processes 16 2.5Gbit/s data streams mutually delayed by multiples of 8 bit, amplifiers for the 20GHz half rate clock, a $LiNbO_3$ CSRZ pulse carver (Agere/Triquint), modulator drivers (SHF communications), and a $LiNbO_3$ data modulator (Agere/Triquint). The signal was transmitted through various fibers.

In the receiver, after passing an EDFA and an optical filter, the signal enters a commercial Mach-Zehnder interferometer (MZI) with a 100ps delay. In our system differential encoding was not implemented nor needed because a 2^7-1 PRBS was transmitted.

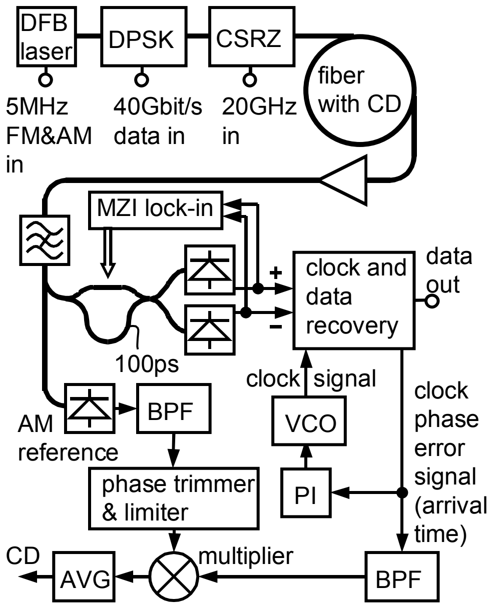

Fig. 2: 40Gbit/s CSRZ-DPSK transmission setup

The interferometer outputs are connected to two photodiodes (u2t). The signal is demultiplexed in a 1:16 clock-and-data recovery (Infineon) with differential input. All 2.5Gbit/s subchannels are bit error free. The half rate clock signals in transmitter and receiver are generated by dielectric resonator VCOs (WORK microwave GmbH).

Parts of the photodiode output signals are tapped off and sent through differential 40Gbit/s amplifiers (Infineon) for subsequent AC power detection (not shown). Maximum RF power is observed when the interferometer phase difference is set correctly. The phase difference is therefore thermally modulated at 400 Hz, and stabilized by integrating the lock-in detected RF power detector output signal.

The DFB transmitter laser is frequency-modulated at 5MHz with a 224MHz deviation, and a parasitic 1.2% amplitude modulation (rms). A low-frequency photoreceiver with bandpass filter detects the AM to provide a reference for a 5MHz lock-in detection of the clock phase detector output signal in the CDR. In the presence of chromatic dispersion (CD), the FM causes a small arrival time modulation which is indicated by the clock phase detector.

Results

The 400Hz lock-in stabilization of the interferometer phase essentially eliminates the impact of a small polarization-dependence of the interferometer phase shift. The eye diagrams at each photodiode are shown in Fig. 3 left. Their difference, i.e. the differentially decoded signal, is seen in Fig. 3 right. The Q factor is 24dB for CSRZ pulses. 8ps-long RZ pulses were also tried and yielded a Q>28dB.

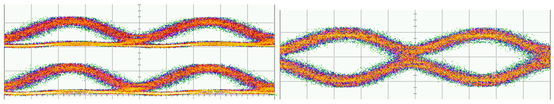

Fig. 3: Back-to-back eye diagrams at interferometer outputs, and difference signal

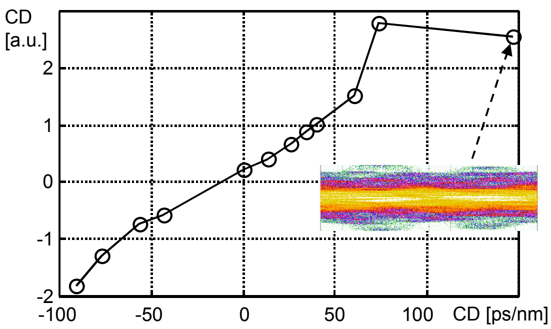

Fig. 4: Chromatic dispersion detection readout vs. actual dispersion. Inset: closed eye diagram at 147ps/nm resulting from interferometer output signal difference

The function of the chromatic dispersion detection was verified by inserting various fiber pieces. Fig. 4 shows the CD readout as a function of true CD in the range -91ps/nm ... +147ps/nm. The readout is fairly linear in the range where the eye diagram is open. The sign of the CD is faithfully returned even when the eye diagram is closed (inset Fig. 4) as long as the clock phase detector works, the PLL locks, and there is a high-enough percentage of correct data decisions. Since the sign is preserved the CD error signal could directly control an adaptive CD compensator via an integral controller.

The readout noise at zero CD ranges from 4ps/nm to <100fs/nm for measurement intervals between 38µs and 157ms (Fig. 5), the 2^7-1 PRBS yielding slightly better results than a 2^{23}-1 PRBS.

Finally the CSRZ-DPSK signal was transmitted over 58km of SSMF, 33km of DSF, and some DCF. Because of a large negative CD at the 1547nm DFB laser wavelength an external cavity laser was used and tuned to 1560nm. The Q factor after transmission was >22dB. The eye diagrams are seen in Fig. 6.

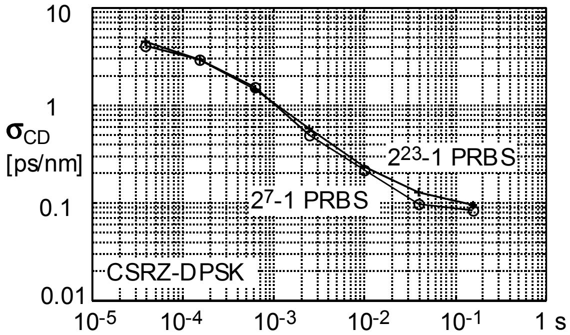

Fig. 5: Standard deviation of measured CD vs. measurement interval, at zero actual dispersion

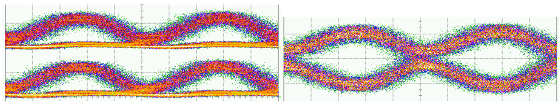

Fig. 6: Eye diagrams like in Fig. 3, but after transmission through 91km fiber

Conclusions

We have presented various practical improvements over previously published 40Gbit/s DPSK transmission systems, related to coding, clock recovery and interferometer stabilization. A small FM applied to the transmitter laser allows to measure chromatic dispersion online, including its sign.

References

1 C. Rasmussen et al OFC 2003 PD18

2 B. Zhu et al OFC2003 PD19

3 J. Marcerou et al OFC2003 PD20

4 J. Cai et al OFC2003 PD22

5 T. Tsuritani et al OFC2003 PD23

6 Mijamoto et al., IEEE J. of Solid-State Circuits, Vol. 34, 1999, pp. 1246-1253

7 D. Sandel et al ECOC2002 Vol. 3 6.1.4