Precise Measurements of Highly Attenuated Optical Eye Diagrams

Przemysław Krehlik, Łukasz Śliwczyński, and Grzegorz Sikorski

***Abstract*—The idea and practical realization of a measurement system dedicated for highly attenuated eye diagrams diagnostics is presented in the paper. It is specially oriented on high-speed modulated optical data transmission signals which amplification is difficult and/or undesired. The presented measurements displayed the usefulness of proposed solution.**

***Index Terms*—eye diagram, optical measurements, noise reduction**

I. INTRODUCTION

ANALYSIS of the eye diagram (called also the eye pattern) is a simple but powerful method of digital transmission channel diagnostics. The eye diagram arises from overlapping many different data patterns time-shifted by an integer number of unit intervals (i.e. serial clock cycles) – see Fig. 1a. Degradation of the digital signal, caused by the transmission channel, may be thus recognized and measured. Some well known cases of signal distortions are illustrated on Fig. 1b.

The simplest way to obtain the eye diagram is to register the data signal with an oscilloscope having long persistence, during the synchronization of the time base from the data clock signal (alternatively divided by any integer factor).

In case of fast optical signals, the best choice is to use the sampling oscilloscope with the optical-to-electrical (O/E) converter integrated with the sampling unit. This solution offers the outstanding equivalent bandwidth up to 70 GHz, with flat frequency response and low group delay dispersion [1]. However, it suffers from relatively high noise, in range of 10 ... 20 μW_{RMS} of equivalent optical power. The noise disturbs or even completely blurs the observed eye diagram when the measured signal is strongly attenuated by long fibers or other optical devices. In some cases the problem may be overcome by using an optical amplifier, or external O/E converter followed by electronic amplifier. Unfortunately, in some situations those solutions could not be used or are suspected of introducing some artefacts affecting the measurement results. Therefore, some method of noise reduction in the eye diagram measurements is desired.

II. THE IDEA OF EYE NOISE REDUCTION

A well known method of noise reduction, used in the measurements of periodic signals on digitising oscilloscopes, is to average many registrations of the same trace (so called boxcar averaging). When the noise is zero mean and uncorrelated in subsequent measurements, the root-mean-square (RMS) of the noise is reduced accordingly to the square root of the number of averaged registrations. In the ordinary eye diagram measurement, however, the overlapping of different patterns on the scope screen prohibits direct averaging.

The presented idea changes the manner of collecting signal samples to allow averaging-based noise reduction. The pattern generator, connected to the input of transmission link under test, outputs a set of different data sequences. Each sequence is repeated a number of times to allow the averaging of particular patterns measured at the tested link output. Finally, all stored averaged patterns are overlapped and shown on "virtual" oscilloscope display – see Fig. 2.

It should be realized that the described method of the eye diagram construction changes in some way the information gathered in the eye diagram. By reducing the measurement noise it clarified all pattern dependent signal distortions (intersymbol interferences (ISI), nonlinear distortions, pattern dependent jitter and so on). At the other hand, however, the averaging reduces not only measurement noise but also any possible random events in the received signal, such as transmitter relative intensity noise (RIN), optical amplifier amplified spontaneous emission (ASE), adjacent signals crosstalks in multichannel systems etc.

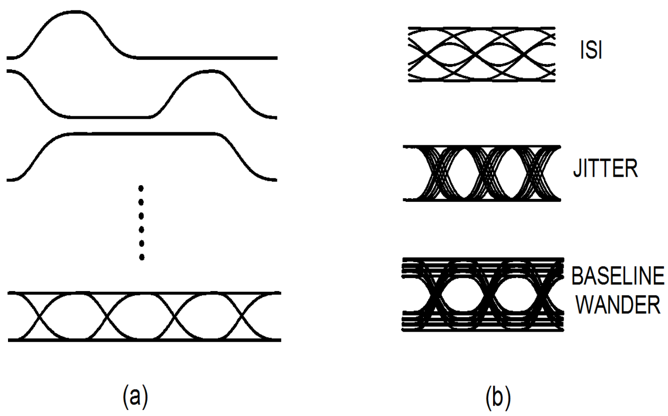

Fig. 1. The idea of the eye diagram construction (a), and common eye distortions (b).

III. MEASUREMENT SYSTEM IMPLEMENTATION

Based on the idea presented above, a measurement system dedicated for measuring highly attenuated optical eye diagrams was built. The system (see Fig. 3) is based on

P. Krehlik is with the Institute of Electronics, AGH University of Science and Technology, Mickiewicza 30, 30-059 Kraków, Poland; e-mail: krehlik@agh.edu.pl.

Ł. Śliwczyński is with the Institute of Electronics, AGH University of Science and Technology, Mickiewicza 30, 30-059 Kraków, Poland; e-mail: sliwczyn@agh.edu.pl.

G. Sikorski graduated from AGH University of Science and Technology in 2007.

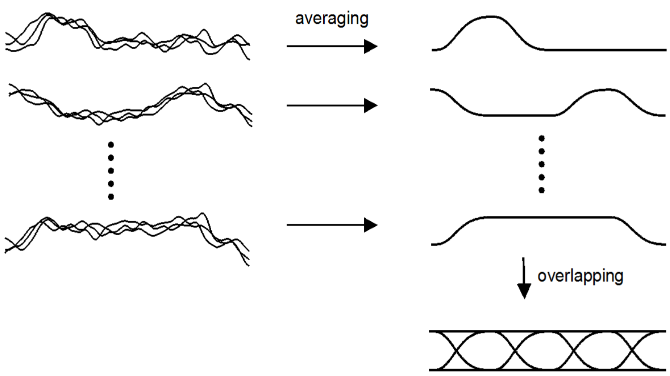

Fig. 2. The idea of eye noise reduction.

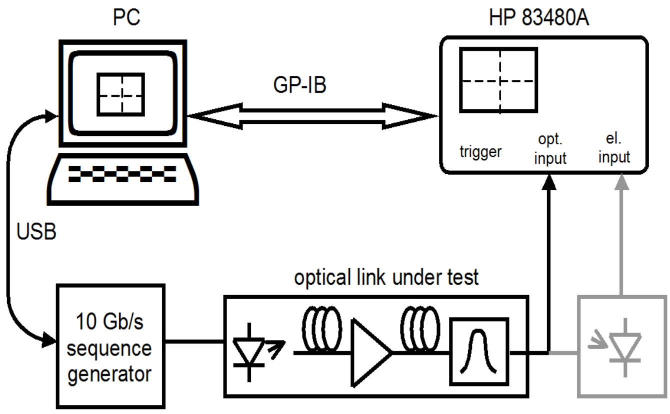

Fig. 3. Block diagram of measurement system.

HP83480A sampling oscilloscope with HP83485B optical plug-in, offering 30 GHz measurement bandwidth. The oscilloscope is connected, via the GPIB interface, with a system software run on personal computer (PC). The software controls also the data sequence generator. The generator repeats the current pattern until it receives a new one from the PC. The actually implemented sequence generator operates with 10 Gb/s output data rate, and produces 16-bit patterns. The tested optical link consists of a transmitter and arbitrary set of optical components, as fibers, optical amplifiers, dispersion compensators, filters etc. Optionally, it may be terminated by O/E receiver for electrical eye diagram measurement.

The entire measurement process is controlled by a dedicated software, written in Matlab environment [2]. After defining the set of data patterns to be used in the measurement, and setting some parameters (as the number of averages of each pattern), the measurement process may be initialized by the operator. Then, subsequent patterns are sent to the sequence generator. Each sequence is repeated at its output for the time needed for the averaging process, performed by the oscilloscope. Next, the resulting averaged output pattern is acquired by GPIB interface and stored on the PC. Then the next pattern is sent to the generator, the oscilloscope averaging memory is cleared and initialized, and so on. Finally, all the patterns got from the oscilloscope are overlapped to form the eye diagram, which is displayed on "virtual" oscilloscope display, emulated by the software on the PC monitor.

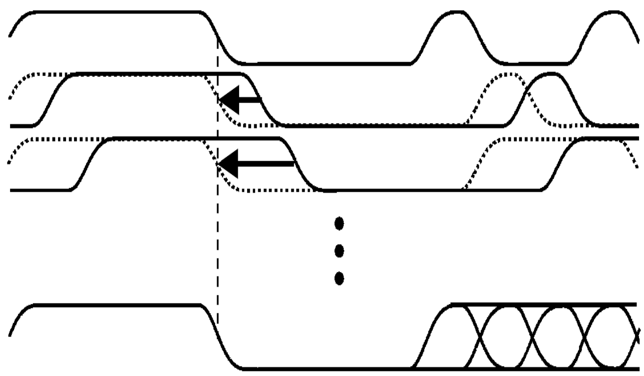

Fig. 4. Aligning of patterns shifted by transmission delay variation.

When testing the system, a generally proper behavior was observed. However, in some cases some malfunction, manifested in the horizontal eye smear was detected. It was found that the problem arises when the tested optical link introduces serious a transmission delay, i.e. it includes long fiber. Because the oscilloscope is triggered by the signal coming from the sequence generator, any drift of the transmission delay results in horizontal wander of the received signal observed on the oscilloscope. As the measurement procedure takes significant time (in the range of a few minutes up to an hour), the subsequently received patterns may be mutually shifted, which blurs the resulting eye pattern. In the case of fiber optic transmission the common reason for the transmission delay drift is fiber chromatic dispersion interacting with temperature dependent laser wavelength. As it was observed, for transmitters with uncooled laser operating in dispersive 1.55 μm window, even a few kilometers of fiber may introduce unacceptable delay instability.

To overcome the problem, an optional procedure performing auto-alignment of received patterns is added. The idea of the alignment algorithm is illustrated in Fig. 4.

In this option the first half of the 16-bit patterns outgoing the sequence generator is reserved for constant reference pattern, consisting of four "1" and four "0" symbols. The remaining 8 bits are changing and used for eye pattern construction. The software automatically recognizes the reference transition and aligns all received patterns before overlapping.

IV. EXPERIMENTAL RESULTS

To illustrate the system abilities, some examples are presented in this section. In the first one the tested transmission link consists of the 10 Gb/s transmitter, based on directly modulated laser operating at 1.55 μm wavelength, two pieces of standard single-mode fiber with dispersion compensating fiber between them. The total fiber length was 110 km. The fiber link presents some residual chromatic dispersion (about 600 ps/nm), caused by insufficient length of the compensating fiber. Because of high attenuation of the set of fibers, the received signal was very weak, and so the eye diagram measured directly on the oscilloscope was completely hidden

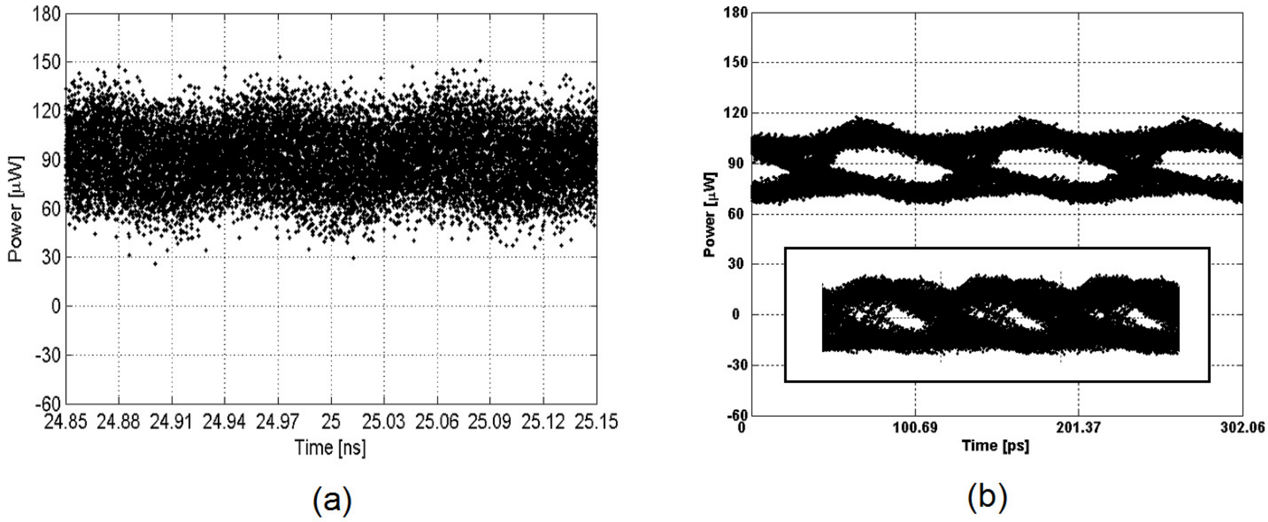

Fig. 5. Eye diagram of weak signal register directly on the oscilloscope (a), and using the described system (b).

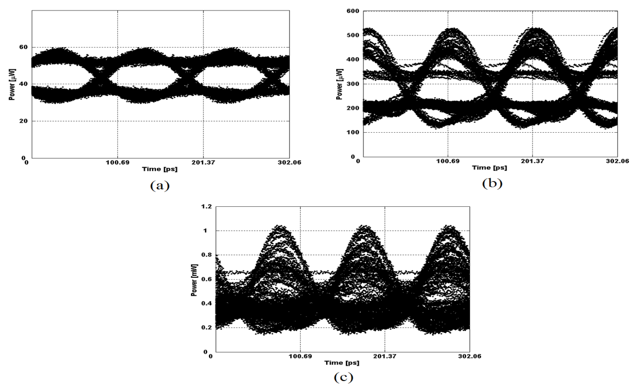

Fig. 6. Eye diagram obtained at the end of same optical link for varying EDFA amplification.

in oscilloscope noise, as shown in Fig. 5a. Using the presented system, the clear eye was obtained, as shown in Fig. 5b. Now some signal distortions, caused by the residual dispersion, may be precisely observed. In the experiment the laser cooler was turned off, so the ambient temperature variations affected the transmission delay. The main eye displayed in Fig. 5b was taken with the auto-aligning option turned on, and the inset shows the smeared eye diagram obtained without aligning.

The eye diagrams presented in Fig. 6 were obtained for a link consisting of the transmitter described above, the boosting erbium doped fiber amplifier (EDFA) and 70 km of dispersion compensated fiber. Three measurements were performed for various EDFA gains. The eye shown in Fig. 6a was obtained for low amplification, resulting in 5 dBm power at fiber input. This time the output eye was clearly opened, with only small over- and undershoots observed. For higher amplification the signal distortions become evident (Fig. 6b), and finally, for even higher amplification, the output eye pattern was completely destroyed (Fig. 6c). This way an evident manifestation of fiber nonlinearities was observed. (The eye diagram measured at EDFA output had still the same shape.) It should be pointed out that the reference eye diagram, taken with the lowest amplification, could not be obtained without the presented measurement system, because of the weakness of the fiber output signal.

V. SUMMARY

A solution for measuring the highly attenuated optical eye diagrams is presented in the paper. It is dedicated for use in situations when the optical or electrical amplification of the received weak optical signal is impossible or is suspected of introducing some undesired artifacts.

The main idea is to repeatedly transmit each data pattern to allow measurement noise reduction by means of averaging, and to overlap all registered patterns afterwards. The idea of coping with the possible transmission delay wander is also proposed. The practical implementation of the measurement system and realized experiments verify the usefulness of the solution.

REFERENCES

[1] "DSA8200 Digital Sampling Oscilloscopes," [online], http://www.tek.com/products/oscilloscopes/.

[2] G. Sikorski, "Stanowisko do automatycznego sterowania i akwizycji danych dla cyfrowego oscyloskopu samplingowego," Master's thesis, AGH, Kraków, 2007.