

# Fast Experimental BER Extraction of 40 Gb/s Optical Signal Impacted by Jitter, ISI and ASE Noise Using Waveform Sampler

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## Abstract

We present a new experimental BER extraction method using a sampling oscilloscope and statistical processing on EDFA noise, photoreceiver noise, jitter and ISI successfully tested on a 40 Gb/s network.

## Introduction

Performance measurement and simulation to achieve a desired Bit-Error Rate (BER) is fundamental for developing optical communication systems. Reliability and efficiency in terms of time consuming BER measurements have become a more and more critical issue because of high quality links associated to ultra high speed transmissions. For example, 100 errors of a 40 Gb/s link operating at a BER of  $10^{-12}$  need about forty minutes to be measured using a direct error counting method with a Bit-Error-Ratio Tester (BERT). This is why, for low BER and very high bit rates, direct measurements are not always used due to long acquisition times and also to the expensive equipment. Many indirect methods, like the Q factor, based essentially on Eye Diagram measurements, have been proposed. Nevertheless, these methods are used as a rough first estimate for BER [1].

We propose a new accurate method to extract the BER of high-speed optical links using a sampling Equivalent-Time Oscilloscope (ETO) taking into account simultaneously EDFA noise, post-detection noise, jitter and Inter Symbol Interference (ISI). This method can be applied to binary modulation formats such as NRZ, RZ or CS-RZ. It is independent of bit rate, and can be used down to very low BER values (below  $10^{-12}$ ).

Our BER extraction method has been successfully tested in the framework of the CARRIOCAS project in the "Pôle de Compétitivité Mondial SYSTEM@TIC". The aim of the undergoing CARRIOCAS project is the demonstration of a low-cost, high reliability 40 Gb/s network, based on dispersion managed optically amplified links.

## Principle of the ETO method

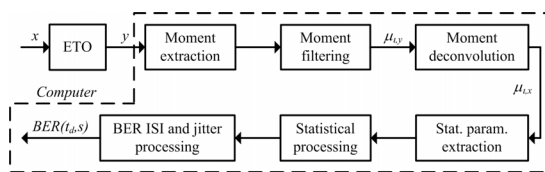


Figure 1: Equivalent Time Oscilloscope (ETO) BER extraction processing method

Fig. 1 shows the numerical BER processing extraction method used to obtain the  $BER(t_d, s)$  of a  $2^n - 1$  bits PRBS signal  $x$ , at the user-defined decision time  $t_d$  and threshold  $s$ .

After optical conversion, the photoreceiver electrical signal  $x$  is sampled with an ETO, which generates sampled waveforms  $y_k$  that are transferred to a computer. Then statistical moments are extracted. These are then filtered to reduce measurement noise. Because of jitter,  $x$  is generally different from  $y$ . The moments of  $x$  are then reconstructed using a moment deconvolution numerical method [2].

Parameters associated to the moments are specific to the statistical laws describing  $x$ . In our processing Gaussian and Non-Central Chi-Square (NCX2) standard statistics can be used [3]. Nevertheless best results are obtained with a new combined statistics: the Gaussian Convolved Non-central Chi-Square (GCNCX2) statistics in order to take into account simultaneously Gaussian thermal and shot noise from the photodiode and non Gaussian ASE noise.

In order to obtain a correct BER estimation, jitter and Inter Symbol Interference (ISI) are taken into account. Jitter and ISI are included at the end of our processing (see fig. 1). Jitter is important when using high speed optical links, causing a reduction of the time margin and increasing BER [4]. ISI, which is a patterning effect, modifies statistics for marks and spaces and makes the standard Q factor inappropriate [5].

## Experimental results

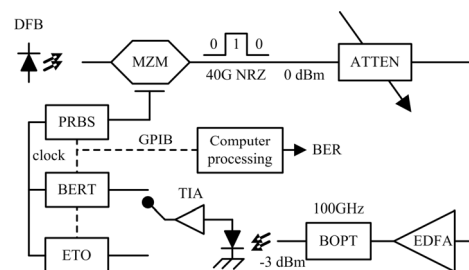


Figure 2: Experimental 40 Gb/s test link with measurements ETO and BERT

The experimental optical test link (see fig. 2) comprises an optical Mach-Zehnder Modulator (MZM) connected to a NRZ 40 Gb/s  $2^7-1$  PRBS generator and a 1550 nm DFB laser. The link is in a back-to-back configuration. The receiver is constituted of a low-noise EDFA, an optical filter and a PIN photodiode followed by a linear Trans-Impedance Amplifier (TIA). In order to compare BER results, the output of the TIA is connected alternatively to our two measuring devices, a BERT (Agilent 81250) and an ETO (Agilent 816100C) with 100 samples per bit.

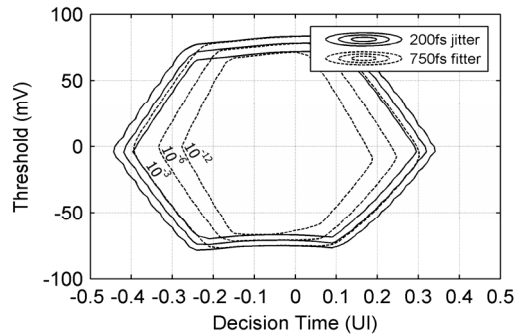


Figure 3: BER contour limits for two jitter levels without jitter removal processing

Higher jitter leads to a smaller time margin. To illustrate this effect we used two ETO timebases with jitter levels of 200 fs, same as the BERT device, and of 750 fs. Results are shown on BER contours, fig. 3.

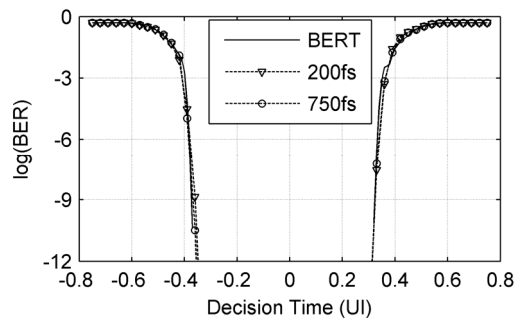


Figure 4: Bathtub curve after jitter removal processing

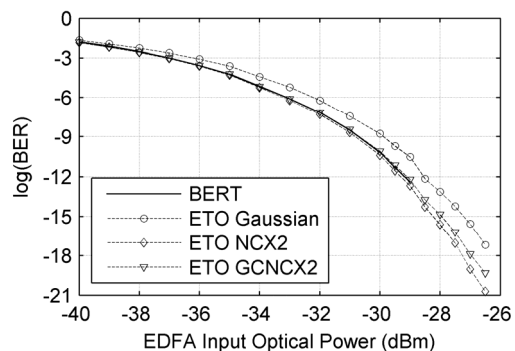


Figure 5: BER as a function of EDFA input optical power for ETO and BERT

As discussed above jitter effects are eliminated using our extraction method. Fig. 4 shows the BER “bathtub curves” for the two jitter levels. These are compared to the one measured directly with the BERT on signal x (back-to-back configuration with negligible link jitter), the results are the same for the same jitter levels (200 fs) between ETO and BERT.

Another experiment measures the BER as a function of EDFA optical input power. The complete processing was used in order to account for jitter and ISI. Fig. 5 shows that, using the ETO method, it has been possible to measure the BER at levels as low as  $10^{-21}$ , whereas using the BERT system one is limited to  $10^{-12}$ . Using Gaussian statistics, BER is overestimated up to two orders of magnitude. On the other hand, NCX2 statistics systematically underestimates BER. Finally, using our GCNCX2 statistics, we find that the BER follows closely the reference BER with log difference below 0.25.

## Conclusions

We have demonstrated a new BER evaluation method including jitter and ISI. In the evaluation process the use of specially tailored GCNCX2 statistics leads to results that are successfully compared with direct BERT measurements on an optically amplified link at 40 Gb/s.

In our ETO BER extraction method, the time needed to make measurements leading to a complete BER contour, constituted of typically 1000 values, is approximately ten minutes, independently of BER value. Using a BERT, measurement time depends on the number of collected errors. In our method the time gain factor for BER contour construction is from 2 to 1000 compared to BERT. A factor 1000 corresponds to the most interesting case of low BER ( $10^{-12}$ ).

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