Digital Signal Processing Algorithm for Signal Analysis and Performance Monitoring in an Optical Communication Link

T V Chabata, R R G Gamatham, H Y S Kourouma, E K Rotich Kipnoo, A W R Leitch, and T B Gibbon

Physics Department, Optical Fibre Research Unit, Nelson Mandela Metropolitan University, P. O. Box 77000, Summerstrand , Port Elizabeth-6031, South Africa. Tel: +27 41-504-2141; Fax: +27 41-504-2573
Email: Tichakunda.Chabata@live.nmmu.ac.za

Abstract: - Digital signal processing (DSP) algorithm is proposed to analyse and monitor the performance of a digital optical communication link. In this paper, an efficient offline and flexible reprogrammable DSP algorithm is developed, to determine the bit error rate (BER) as a measure of performance of an optical communication system. The 10 Gbps optical signal transmitted over the fibre is received, sampled and reconstructed in the digital electrical domain. Further a DSP algorithm is implemented offline to normalise and quantise the signal before it is digitized into respective transmitted bits. The DSP technique is an indispensable technology for next generation ultra-fast optical fibre communication. The developed offline DSP algorithm has outstanding advantages such as guaranteed accuracy, perfect reproducibility and high reliability. The effectiveness of the proposed algorithm is quantitatively verified by measuring the BER for different transmissions.

1. Introduction

The ultimate goal of the optical signal transmission is to achieve the acceptably low bit-error rate (BER) between any two nodes in an optical network. Recently deployed optical fibre communication systems exploit intensity modulation and direct detection (IMDD) to transmit information [1]. The drive towards higher spectral efficiency in optical fibre systems has generated interest in digital signal processing (DSP). Digital signal processing technique encompasses computer science technology, communication science and mathematics in analysing a signal [2].

Recent advances in analogue-to-digital (A/D) conversion technology make it possible to use DSP techniques to demodulate high-speed optically modulated signals. Pairing DSP with IMDD, optical receivers have attracted attention recently due to increased CPU memory and clock speed. Nowadays it is possible to use a commercially available computer to handle the light wave data sequence.

This article describes the actual modulation and detection methods in order to explain how an optical receiver including offline processing works. DSP algorithms for signal reconstruction and the subsequent BER computations are done as a measure of performance of intensity modulated optical communication link. Reconstructing the signal involves filtering, sampling, normalising, quantising and digitizing the continuous signal into a discrete time signal. The back to back BER measurements are important in the determination of the receiver sensitivity at a set threshold error value.

2. Theory

An optical communication link comprises of a transmitter, transmission medium and a receiver. The main purpose of the optical receiver in terminating the light wave path is to convert the signal from optical to electrical domain. The obtained electrical signal is then processed appropriately to recover the data being transmitted. The optical signal generated by the semiconductor laser has to be modulated by the information-bearing signal before being transmitted over the optical fibre. The mapping of the data onto the transmission signal is achieved by either directly modulating or externally modulating the bias current of semiconductor laser.

Through the external modulation process, one of the parameters of the continuous wave signal, used as a signal carrier, is varied in accordance with the information-bearing signal. A monochromatic electromagnetic wave is commonly used as a carrier, and its electrical field *E(t)* can be represented by

$$E(t) = pAcos[\omega t + \varphi] \quad [1]$$

where parameters A, ω *and* φ are amplitude, frequency, and phase respectively. Parameter *p* denotes the polarization orientation [3]. Each of those parameters can be used to carry information, and the information-bearing signal can be either continuous wave or discrete.

In a digital optical communications, bit-error rate (BER), defined as the ratio of bits in error to total number of transmitted bit at the decision point, is commonly used as a figure of merit. In that sense, the receiver sensitivity is defined as the minimum required received optical power to keep BER below a given value [3].

3. Experimental setup

The experimental setup is shown in figure 1. A 1550 nm WDM laser signal is intensity modulated at 10.3 Gbps and transmitted through a single mode fibre.

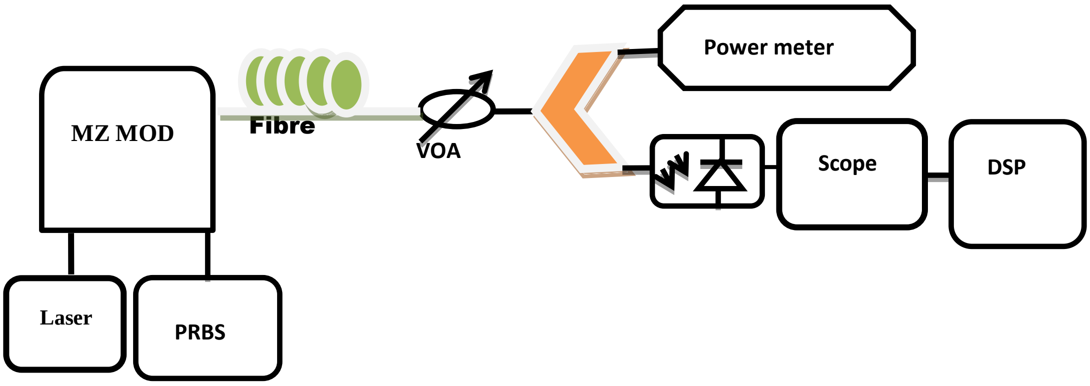

Figure 1: Experimental setup for transmitter and a single ended detection receiver [VOA- variable optical attenuator, MZ- Mach-Zender]

A variable optical attenuator controls the power of the signal prior to detection and conversion to an electrical signal by the photodiode. The Agilent oscilloscope was used to acquire a measurement burst of the received transmitted data, which is then transferred to a computer for offline processing. The received continuous time signal is represented with a sequence of numbers representing the amplitude of the continuous time signal at a specific instant in time. The received electrical signal is processed offline using relevant DSP algorithm to determine the BER as the measure of performance of the optical fibre transmission link.

4. Results and Discussion

For intensity modulation, the receiver scheme comprises of a 3 dB coupler, a single photodiode, oscilloscope and the digital signal processing algorithm. A 2^7-1 pseudo random binary sequence (PRBS) bit pattern sequence is transmitted at 10.3 Gbps at different attenuation values for back to back transmission. The developed DSP algorithm comprises of four important parts. The function of the first part is to load the digital data saved in the sampling scope to an offline processing computer. The second part normalises and digitizes the continuous signal into discrete bits. The third part generates the pseudo random binary sequence (PRBS) (2^7-1) bit pattern and then compares it to the recovered data bits to determine the bit error rate. The fourth and last part of the algorithm plots the eye diagram.

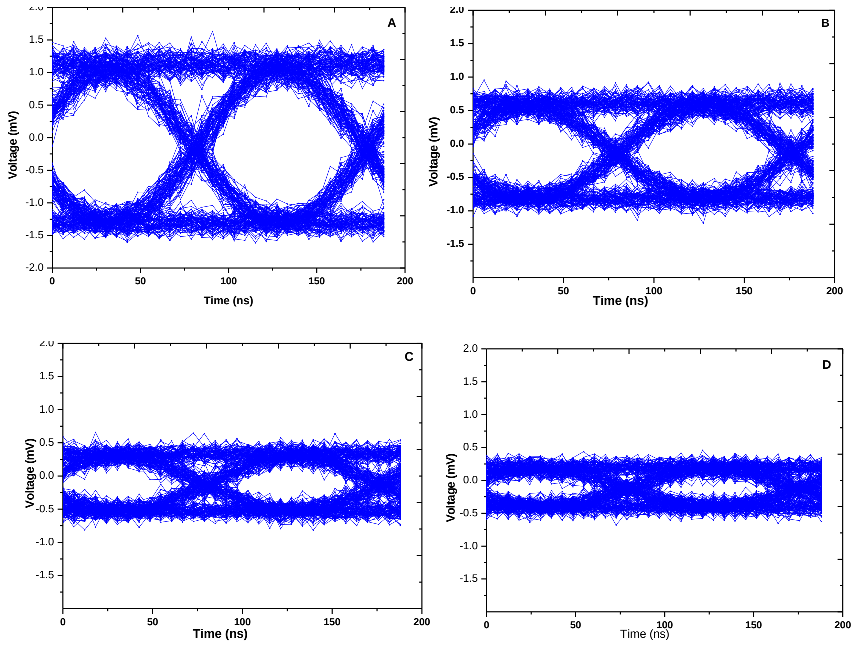

Figure 2: DSP Eye Diagram plots at different Power values

An eye diagram is a quick way of assessing the signal quality. Figure 2 A to D shows the eye diagram plots at different optical power values as indicated on figure 3 B. The eye closure suggests degradation in the signal quality due to attenuation. Information can be easily and reliably recovered from the free transmission eye diagram (figure 2 A) and very little or no information can be recovered from the closed eye diagram in figure 2 D.

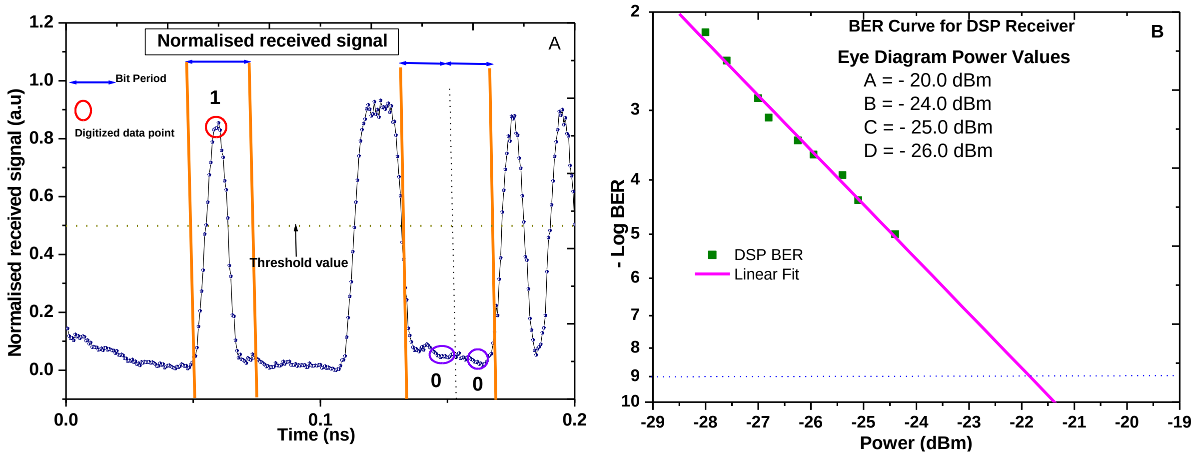

Figure 3: A. DSP normalised and digitized signal as captured from the digital storage oscilloscope

B. DSP back to back BER curves for different received optical powers.

Digital signal processing is the process of extracting useful information from an incoming signal. The received, loaded data is normalised to reduce the large data range to between zero and one for easy and accurate computations. The algorithm sums up the first three bits from the middle of the bit period. The sum is compared to a set threshold to determine whether its logic value one or zero. Any value greater than the threshold value is assigned a logical value '1' and any value below the threshold is assigned a logical zero '0' as shown in Figure 3 A.

A total of 200 000 bits was used for the bit to bit comparison between the transmitted and received signals. Figure 3 B shows the back to back DSP bit error rate curves for different attenuation values. The extrapolated receiver sensitivity value of -21.8dBm is obtained at a threshold BER value of 10^{-9}.

5. Conclusion

The developed DSP algorithm is an effective and efficient method to determine the BER, due to its cost, consistency, accuracy and reproducibility. Conclusively the developed DSP algorithm for signal reconstruction and subsequent BER calculation for intensity modulated and demodulated optical link was successfully implemented.In future DSP algorithms are going to be developed for advanced modulation formats to compensate for transmission impairments in the fibre.

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