Chromatic dispersion monitoring scheme with very high dispersion monitoring window at 40 Gbit/s

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***Abstract*— The method presented is based on a scheme previously implemented, which uses a post-detection method of dispersion monitoring. We used this method together with another one to extend the monitoring window. The later one measures the Q-factor by capturing eye diagrams with high speed electro-optical sampling. This allowed us to measure the quality factor, here used to tick out correct dispersion. We show that with this method it is possible to obtain monitoring windows up to 2040 ps/nm at 40 Gbit/s, using the RZ format.**

I. INTRODUCTION

Group Velocity Dispersion (GVD) is a major limitation in optical communication systems. As bit rates increase dispersion tolerance is lesser and lesser and also dispersion monitoring window is smaller. Chromatic dispersion monitoring techniques have been widely studied during many years. Some of these techniques are based on monitoring the magnitude of AM pilot tones [1] [4], non-linear effects in highly non-linear fiber [6] [8], phase-shift detection [5], two-photon absorption [7], among other. A dispersion monitoring method is evaluated by two parameters: its monitoring window and dispersion resolution. The methods aforementioned do not have dispersion monitoring windows larger than 180 ps/nm and this is just for particular modulation formats. Other methods not mentioned have larger monitoring windows, but at the high cost of reducing the dispersion resolution. The importance of dispersion monitoring window is demonstrated when we are measuring the accumulated dispersion of an optical fiber link with 120 km and we have approximately 2040 ps/nm of accumulated dispersion, that needs to be monitored and compensated. Residual dispersion is also important, because for a 500 km optical fiber link, a temperature change of $40\,°\mathrm{C}$, can induce a residual dispersion of 48 ps/nm. Dispersion resolution is also important, because for data rates equal or higher than 40 Gbit/s, a small change in chromatic dispersion, can cause a 1 dB power penalty [4].

In this paper we measure the Q-factor to enlarge the monitoring window of a method previously implemented [4]. To measure the Q-factor we used high speed electro-optical sampling to capture eye diagrams as shown in Fig.1, following the method proposed by [2] and [3]. The Variable Dispersion Compensator (VDC) controller algorithm shown in Fig.1 is used to shift the dispersion, in order to find its correct value. f_{clk} is the clock frequency, equal to the bit rate f_s, λ is the wavelength, T is the period of the residual chromatic dispersion variation, with the power of the clock frequency component. The algorithm start to shift the accumulated dispersion between $D_{fiber} - \frac{T}{2}$ and $D_{fiber} + \frac{T}{2}$, where D_{fiber} is the dispersion fiber. $-\frac{T}{2}$ and $\frac{T}{2}$ is the dispersion interval set by VDC2. We shift the dispersion set with VDC2 by ΔT, between $-\frac{T}{2}$ and $\frac{T}{2}$, where ΔT is equal to:

$$\Delta T = \frac{\frac{T}{2} - \frac{-T}{2}}{25(\frac{1}{2} + \frac{T}{2T_{1550,40}})} \tag{1}$$

and $T_{1550,40}$, is equal to T, when λ is equal to 1550 nm and f_s is equal to 40 Gbit/s. We find from those values of dispersion, the minimum amplitude of the clock component power, at the output of the Band-Pass Filter(BPF) shown in Fig.1and register the corresponding dispersion. Then we find the Q-factor for all values of dispersion T spaced from this last one. We know that one of this values will be equal to D_{fiber} and additionally that this value will have the highest Q-factor. Then we register this value as the correct value of dispersion.

We expose in section II and section III, all the theory related to Q-factor measuring and the operation principle of a post-detection method of dispersion, respectively. In section IV we present the results and in section V the conclusions are drawn.

II. Q-FACTOR MEASUREMENT

In this section we discuss the approach we used to measure eye diagrams and explain all the theory related with the *Q-Factor Monitoring Block*. We used asynchronous under sampling to capture the eye diagrams, so the relationship between the bit rate f_s and the sampling frequency f_c is n/m, where n and m are natural numbers and $n < m$ [2] as expressed by equation (2):

$$f_c = \frac{n}{m} f_s \pm a \tag{2}$$

a is the offset frequency which enables the capture of the sampling points at different bit amplitudes and thus produce eye diagrams. The eye diagram uses approximately m/n bits of the signal, to take one sampling point for it. After k sampling points the waveform of one bit is produced. After approximately $jk\frac{m}{n}$ bits, the eye diagram is composed of a representation of j bit waveforms superimposed from time zero over a specific interval. In the synchronous sampling technique, f_c is determined trough hardware synchronization

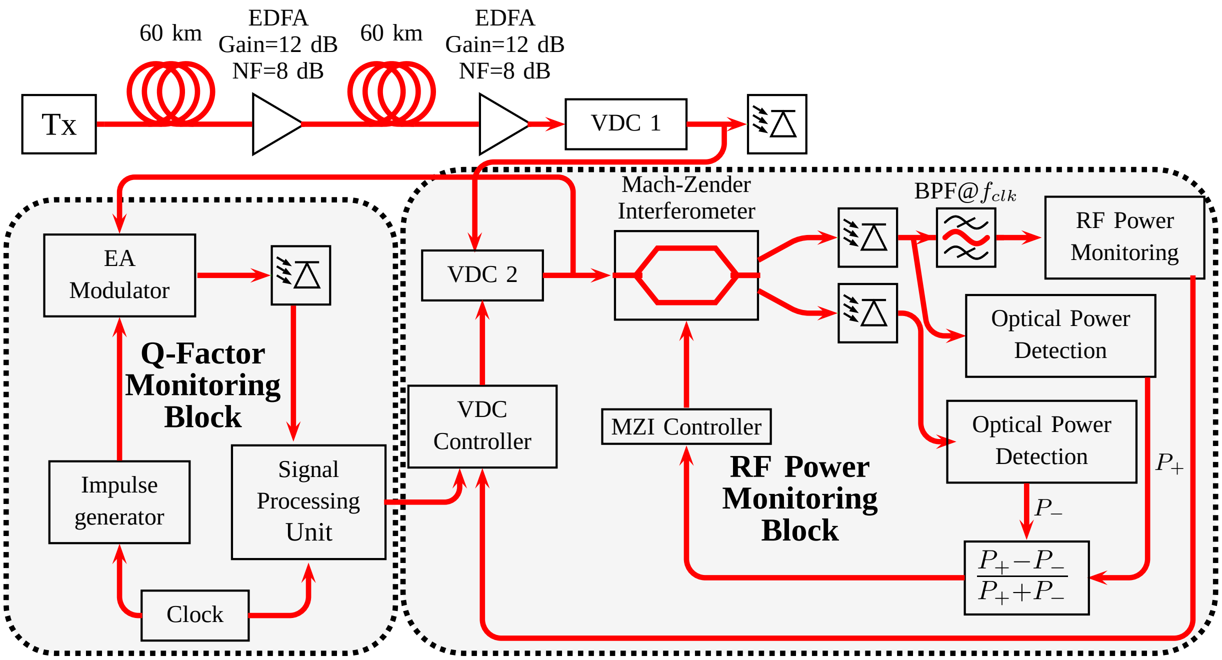

Fig. 1. Simulation setup. The scheme is taken from [4], just adding the electro-optical sampling to obtain asynchronous eye diagrams and measure the Q-factor. The *Q-Factor Monitoring Block* use an Electro-Absorption(EA) Modulator, to modulate the impulses used to sample the optical signal

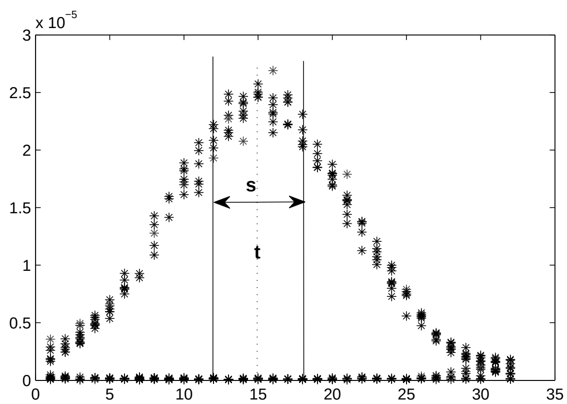

Fig. 2. Opened eye diagram, taken from an RZ signal format, through software simulation, using the method aforementioned

with f_s and by satisfying (3):

$$T_{step} = \frac{1}{f_c} - \frac{1}{\frac{n}{m}f_s} = \frac{1}{kf_s} \quad (3)$$

where T_{step} is the sampling time interval and k is the number of sampling points for each bit slot. If we solve (3) in order to f_c we obtain (4):

$$f_c = \frac{f_s}{\frac{1}{k} + \frac{m}{n}} \quad (4)$$

From (2) and (4), we get (5):

$$a = \frac{\frac{n}{m}^2}{k + \frac{n}{m}} f_s \quad (5)$$

Further considerations are presented in [2]. In Fig.3 is shown how to obtain opened eye diagrams with this method.

In Fig.3 a) k=8, j=1 and n/m=1, so $a = \frac{1}{9}f_s$ and $f_c = \frac{10}{9}f_s$. At this sampling frequency we can plot a sine wave, representing one sine wave of the signal. f_c assures that we can get sampling points at different amplitudes of the sine wave signal. In Fig.3 b) a random signal is shown. In this example k=5, j=2 $a = \frac{1}{6}f_s$ and $f_c = \frac{7}{6}f_s$. At this sampling frequency, we assure that we can get five points, at different amplitudes of the signal waveform, sufficient to represent an opened eye diagram as observed in Fig.3 c). In Fig.3 c) we choose to represent point F at the end of the opened eye diagram instead of being superimposed with point A. Parameter Q_t is estimated from the opened eye diagrams, captured by the asynchronous sampling aforementioned. Parameter Q_t is defined by:

$$Q_t = \frac{\mu_1 - \mu_0}{\sigma_1 + \sigma_0} \quad (6)$$

where μ_i and σ_i are the mean and standard deviations of the mark(i=1) and space(i=0) level distributions of the amplitude histograms, respectively. In Fig.2 we present an opened eye diagram taken from simulation of an RZ signal format using the method aforementioned. In this case k=32, n/m=1/5 and j=12, for a bit rate of 40 Gbit/s. We see that this method is able to produce fairly opened eye diagrams. *s* is the time window, centered at *t*, used to take the sampling points, that are within it, to construct asynchronous amplitude histograms.

III. Operation Principle of a Post-Detection Dispersion Method

It is well known that after transmission and detection, the magnitude of a clock component will change with the total accumulated dispersion of the optical link. Optical fiber dispersion causes a time delay between the upper and lower sideband modulated clock components. In a pre-detection scheme the detected chromatic-dispersion-dependent radio frequency(RF)

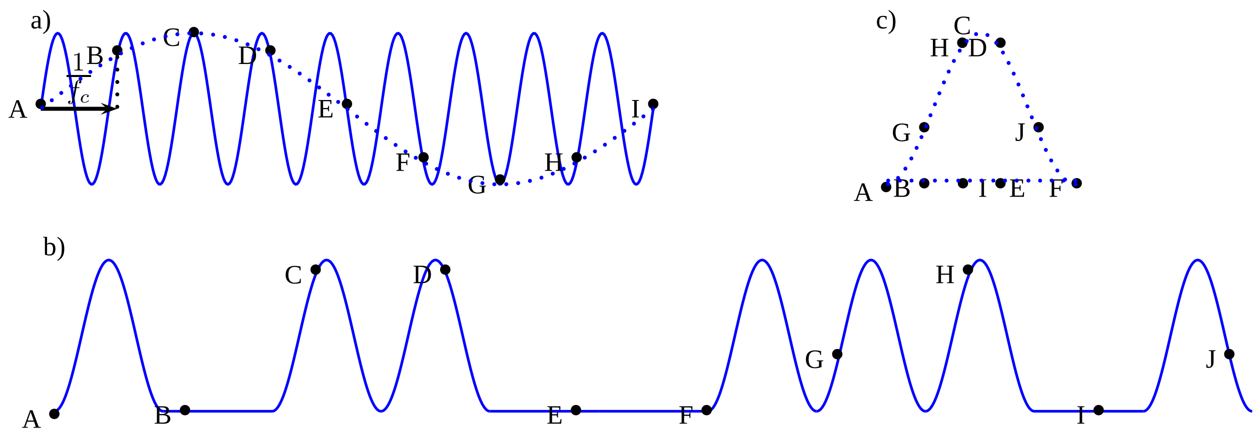

Fig. 3. Illustrative figure of the method for measuring the Q-factor and depicting opened eye diagrams. In a) a sine wave is depicted taking just one point of each sine wave signal. In b) a random signal is shown and in c) an opened eye diagram is depicted with the sampling points taken from b)

power of an AM modulated clock-power frequency can be expressed as [4]:

$$P_{AM} = \frac{1}{2}\left\{\Re P_o m \left| cos\left(\frac{\pi\lambda^2 DL}{c} f_{clk}^2\right)\right|\right\}^2 R_L \quad (7)$$

where P_o is the averaged received optical power, before the photoreceiver, $\Re$ is the responsivity, R_L is the resistive load of the optical receiver, m is the root mean square(rms) modulation index of the amplitude modulator, c is the speed of light in vacuum, λ is the operating wavelength, D is the fiber dispersion parameter, and DL is the total accumulated dispersion. (7) shows that the variation of the AM modulated clock-power frequency, varies sinusoidally with the total accumulated dispersion. According to (7) we can see by the cosine argument, that the period of variation of the clock-power frequency with accumulated dispersion in ps/nm is:

$$T = \frac{c10^{-3}}{(f_{clk}10^{-12})^2\lambda^2} \quad (8)$$

In a pre-detection method of dispersion we want to find what is the maximum clock component power, but considering sinusoidal behavior of (7), we cannot distinguish different maximums, so the monitoring window will be between $-\frac{T}{2}$ and $\frac{T}{2}$. The same occurs in a post-detection scheme, like the one used in this paper, but instead of trying to find the maximum clock RF Power, the post-detection scheme tries to find the minimum. This brings some advantages because in a pre-detection scheme, when the accumulated dispersion is small, the magnitude of the clock component remains almost constant, and as a result , the frequency of the clock component needs to be increased to improve the resolution sensitivity($\Delta P_{AM}/\Delta DL$ in dB/ps/nm) near zero accumulated dispersion. Also requires a higher bandwidth photodetector and costly microwave/millimeter wave components and reduces the effective system spectral efficiency. A post-detection method of dispersion improves these problems, because we have higher sensitivity, even in the presence of small dispersion, and can use lower cost components and

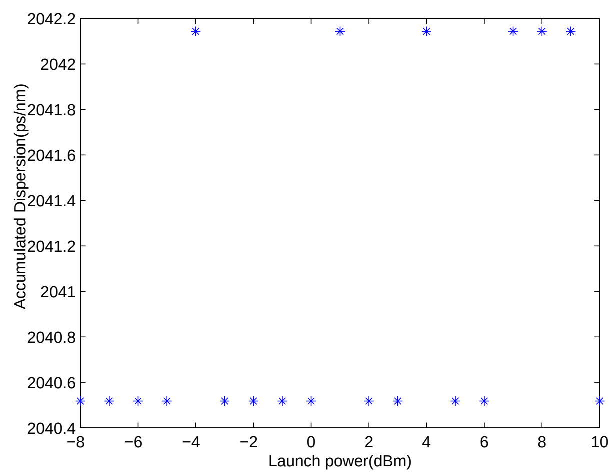

Fig. 4. Measured accumulated dispersion versus launch power

lower bandwidth photodetector [4]. We used a Mach-Zender Interferometer(MZI) before a photodetector to build a post-detection scheme, as shown in Fig.1.

IV. Results and Discussion

For the first simulation presented in Fig.4 we varied the laser launched power, and monitored the chromatic dispersion. Some methods behave fairly when facing different laser launched power, but others do not. The simulation setup was the one shown in Fig.1. $f_c lk$ is equal to 40 GHz, or equal to the bit rate frequency f_s, 40 Gbit/s. We used the RZ(50%) modulation format. The expected accumulated dispersion is 2040 ps/nm. As can be seen from Fig.4, we have correctly measured the accumulated dispersion, using a large range of optical powers, so the method is transparent to this factor.

Then, we examined the accuracy of the method when using different modulation formats. We used 0 dBm of launched power, 18.6 for the OSNR at zero dispersion, f_{clk} equal to 40

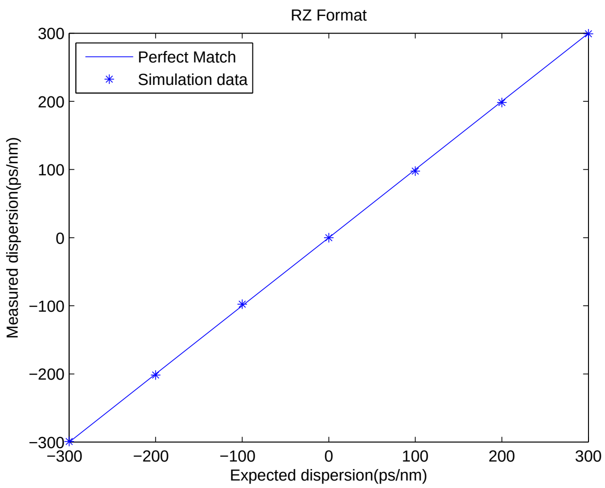

Fig. 5. Simulation data obtained with the RZ format

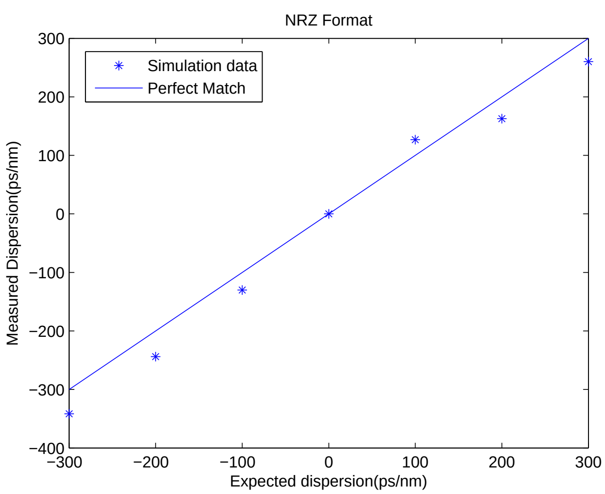

Fig. 6. Simulation data obtained with the NRZ format

GHZ, the same frequency as the bit rate f_s 40 Gbit/s , varied the residual dispersion using VDC1 and VDC2, between -300 ps/nm and 300 ps/nm, and monitored the dispersion variation.The results are shown in Fig.5 and Fig.6. The method behaves well for the RZ format, because the clock component is bigger than the noise present at this frequency, but for the NRZ format, the noise overcomes the clock component and the method does not behave so well.

V. Conclusions

We present a novel post-detection method of dispersion and Q factor measuring to enlarge the dispersion monitoring window. The method was able to measure accumulated dispersion 2040 ps/nm, using OSNRs higher or equal to 9 dBs. The method showed very good behavior using RZ format, but do not behave so well using NRZ format.

Acknowledgments

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