Simulation of a Chromatic Dispersion Monitoring Scheme Using an Optical Delay-and-Add Filter and a BER Analyser

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***Resumo* – É proposto um novo método de pós-detecção de dispersão, baseado num esquema previamente implementado, e que utiliza adicionalmente um medidor de taxa de erros (BER), que permite o alrgamento da janela de monitorização. O método de monitorização foi testado com velocidades de transmissão até 40 Gbit/s. Demonstrou ter janelas de monitorização de pelo menos ± 300 ps/nm, assim como a capacidade de se adaptar a diferentes formatos de modulação, desde que tenham um espectro simétrico. O método demonstrou também elevada sensibilidade (1 dB/(ps/nm)).**

***Abstract* - A new postdetection method of dispersion is proposed, based on a scheme previously implemented, and that additionally uses a Bit Error Rate (BER) analyser, which allows the extending of the monitoring window. The monitoring method was tested with transmission rates of up to 40 Gbit/s. It showed monitoring windows of at least ± 300 ps / nm, as well as the ability to adapt to different modulation formats, with symmetrical spectrum. The method also allowed high sensitivity (1 dB/(ps/nm)).**

I. INTRODUCTION

Chromatic dispersion (GVD) is one of the major limitations in optical transmission links, due to the imposed maximum optical fibre length for a considered bit rate. Chromatic dispersion monitoring techniques have been widely studied in recent years.

Some of these techniques are based on monitoring of the magnitude of AM pilot tones [1], non-linear effects in highly nonlinear fibre [3][5], phase-shift detection [2], two-photon absorption [4], among other. With these techniques it was possible to measure a GVD range of ± 150 ps/nm, for transmission rates up to 40 Gbit/s. Changes in temperature, fibre stretching, can produce dramatic changes of chromatic dispersion in long transmission links, such as transatlantic optical links. For this reason larger monitoring windows are therefore essential to reduce the costs of transmission in optical fibres at high transmission rates and to allow the viability of such links.

In this paper we propose a method that can extend this value to at least ± 300 ps/nm, by monitoring the Q factor, in all minimum points of the AM pilot tone magnitude (depicted in Fig. 2 and 3), using a optical delay-and-Add Filter (DAF) and a BER analyser (schematic in Fig.1). Larger monitoring windows are also possible. Simulation results showed that for 10 fibre trunks of 50 kms each, completing 500 km, using in-line amplifiers with gain of 10 dB the method still working. We get an error relatively to the expected value of dispersion of 7 ps/nm. This means that the simulated monitoring window extends to a value larger than 7500 ps/nm at 40 Gbit/s, keeping high resolution.

This method is based in the schematic proposed by [1].

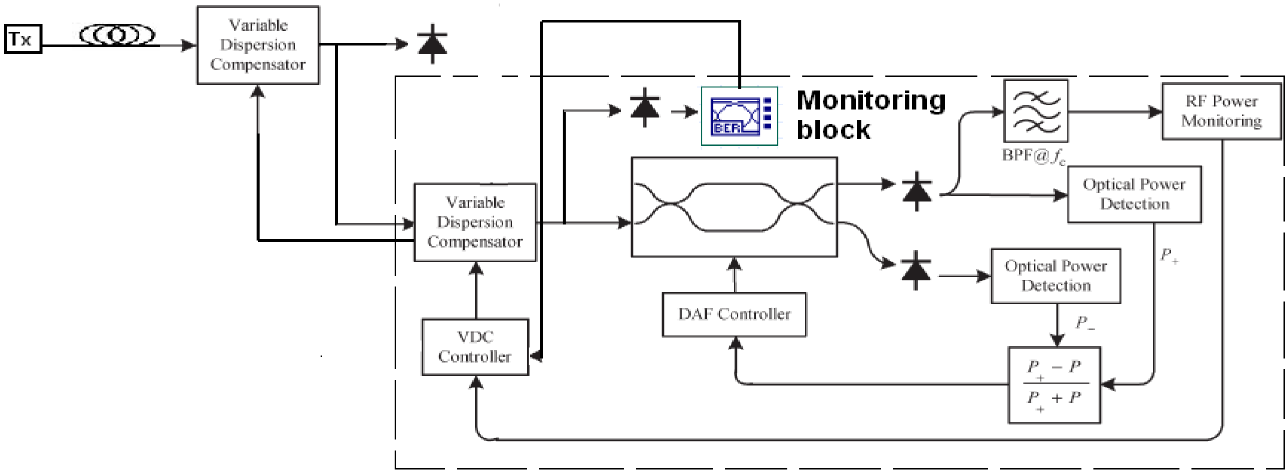

Fig. 1 Complete monitoring scheme based on [1]; additionally we use a BER analyser to extend the monitoring window.

According to [1] the expression that relates the dispersion with the amplitude of one pilot tone (or the magnitude of the clock component for XRZ modulations) in the constructive port of the DAF, when $\tau = \tau_0$ ($\tau_0 = \frac{1}{2 f_p}$), is as follows:

$$P_{AM,DAF} = \frac{1}{2}\left\{ RP_0 mK^2 \left| \sin\left(\frac{\pi\lambda^2 DL}{c}) f_p{}^2 \right) \right| \right\}^2 R_L \qquad (1)$$

where R is the responsivity of the photodetector, P_0 is the average received optical power, m is the modulation index of the AM modulator, $K = \frac{1}{\sqrt{2}}$ is the transmittance of the DAF, λ is the wavelength, DL is the total residual dispersion, c is the speed of light in vacuum, f_p is the frequency of the pilot tone or, for XRZ modulations, the frequency of the clock/AM pilot tone component, R_L is the load resistance of the optical receiver and τ is the delay parameter of a Mach-Zender interferometer.

Theoretically, for $\lambda = 1550nm$ and f_p=40 GHz the power variation associated to the pilot tone, as a function of the residual dispersion DL, is as depicted in Fig. 2.

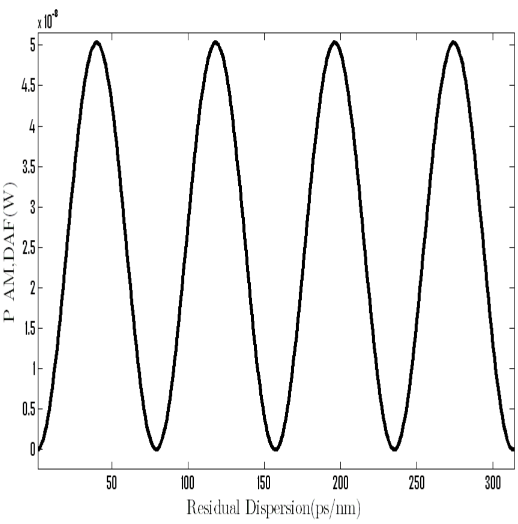

Fig. 2 Power amplitude of the clock/pilot tone component vs dispersion

Simulation results (Fig.3) comproove that periodicity, with period T given by:

$$T = \frac{c.10^{-3}}{((f_p.10^{-12})^2.\lambda^2)} \text{ (ps/nm)} \qquad (2)$$

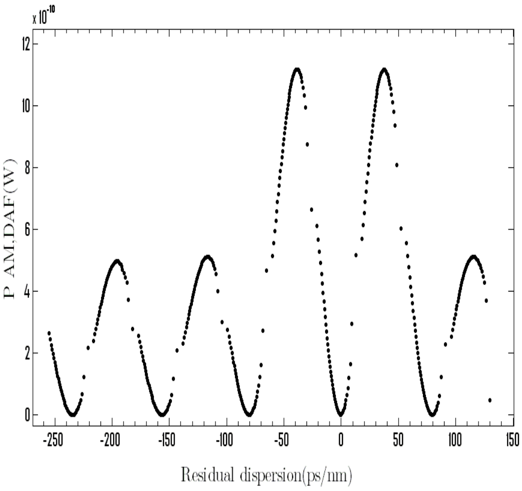

Fig. 3 Simulation results relating dispersion with AM pilot tone power amplitude

The monitoring window in predetection and postdetection methods , using AM Pilot tones, is within $-\frac{\pi}{2}$ and $\frac{\pi}{2}$ as can be seen in Figs 4 a) and b), respectively, which is approximately $\pm 39 ps/nm$ for λ=1550 nm and f_p=40 GHz in silica fibre.

a) b)

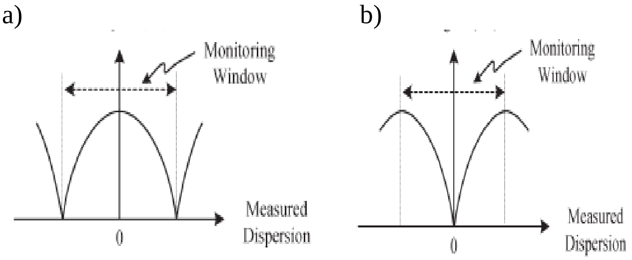

Fig. 4 Predetection (a) and postdetection (b) monitoring windows [1]

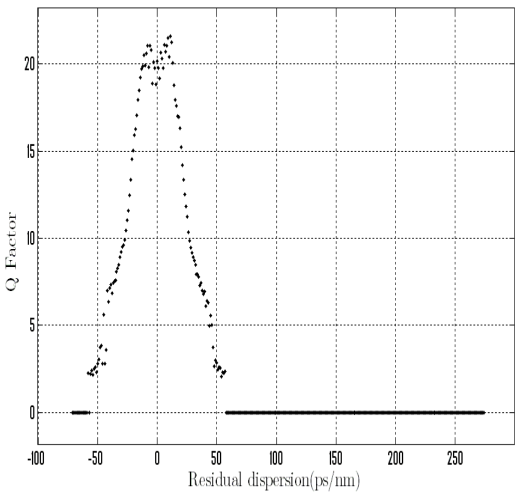

Fig. 5 Q factor versus dispersion

To accomplish the goal of extending the monitoring window we substituted the equation (1) for the equation (3):

$$P_{AM,DAF} = \frac{1}{2}\left\{RP_0 mK^2 \left|\sin\left(\frac{\pi\lambda^2 DL}{c}) f_p{}^2 + n\pi\right)\right|\right\}^2 R_L \quad (3)$$

where n is a negative or positive integer.

If we solve the equation for DL, we get equation (4):

$$DL = \left(\sin^{-1}\left|\frac{\sqrt{\frac{2.P_{AM,DAF}}{R_L}}}{RP_0 mK^2}\right| - n\pi\right).\frac{c}{\pi\lambda^2 DLf_p{}^2} \quad (4)$$

The variation of Q with the dispersion is shown in Fig. 5. When the residual dispersion is zero the Q factor is near maximum, so we can use that information, to get n value, corresponding to the right value of residual dispersion. We do this using the flowchart of Fig. 6.

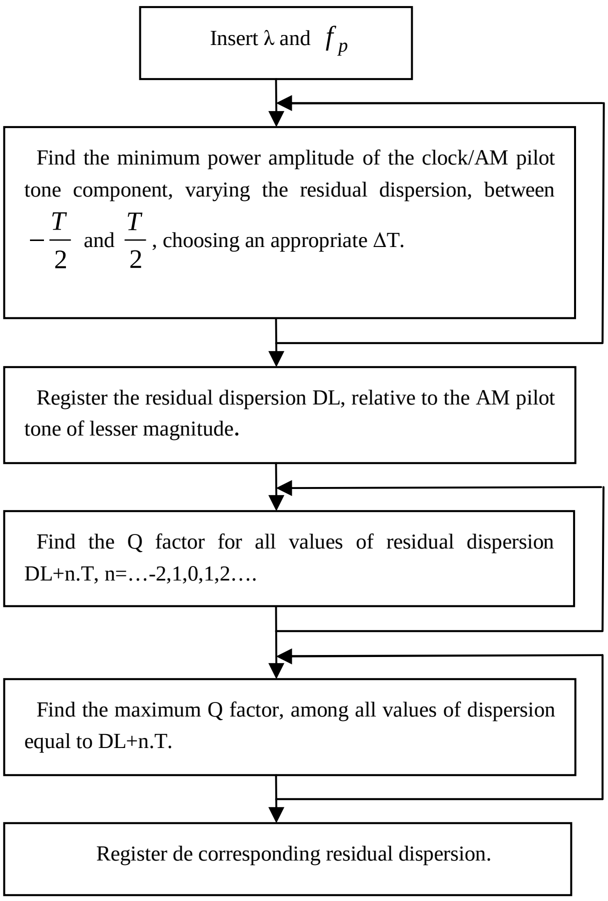

Fig. 6 Flowchart

II. PREDETECTION AND POSTDETECTION METHODS BASED ON AM PILOT TONES WITH AND WITHOUT DAF

It is well known that there is a variation on the magnitude of an AM pilot tone, with dispersion. This is because dispersion causes a time delay, between the upper and lower sidebands of the AM pilot tone, causing consequently a phase change. In a predetection scheme the magnitude of the AM pilot tone is measured, to monitor the residual dispersion, while in a postdetection scheme, when the magnitude of the AM pilot tone is zero, the zero fibre dispersion is detected.

In a predetection scheme the magnitude of an AM pilot tone is related to residual dispersion by the following equation [1]:

$$P_{AM} = \frac{1}{2}\left\{RP_0 m\left|\cos\left(\frac{\pi\lambda^2 DL}{c}) f_p{}^2\right)\right|\right\}^2 R_L \quad (5)$$

The predetection schemes have the disadvantage, that when the residual dispersion is small, the AM pilot tone remains nearly constant and as a result it is necessary to increase the frequency of the pilot tone to increase the resolution [1].

To solve this problem we use the scheme in [1], using a Mach-Zender interferometer, as a DAF. We add to that scheme a BER analyser, as shown in Fig.6, to extend the monitoring window, by measuring the Q factor, in all minimum points of the AM pilot tone magnitude.

Fig. 1 shows the complete monitoring scheme.

The frequency response at the constructive port of the DAF is written as follows[1]:

$$H_+(f) = |H_+(f)|e^{j\Phi_+(f)} = \frac{j}{2}\left(e^{-j2\pi\tau f} + 1\right) \quad (6)$$

The main idea of this method is to let the phase difference between the two pilot tone sidebands be π, as shown in Fig. 7.

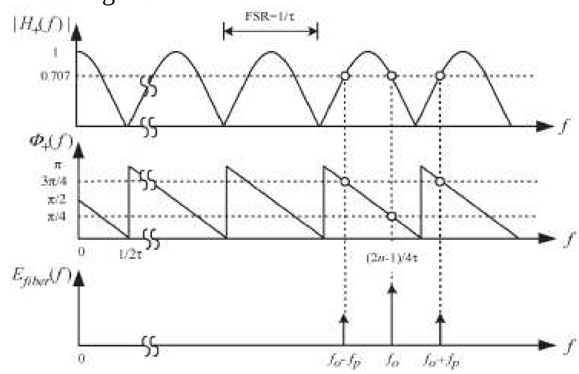

Fig. 7 Optical amplitude and phase responses of a DAF at its constructive port. The electric field spectrum is also depicted [1].

When this occurs, the two sidebands cancel each other which means that we have zero fibre dispersion. Another objective that comes from the use of a DAF, is to increase the resolution sensitivity. This means that even when there is only a small amount of residual dispersion the magnitude of the pilot tone will change significantly. To fulfil these goals we need two conditions to be satisfied [1]:

$$1)\ \tau = \tau_0 = \frac{1}{2 f_p}$$
$$2)\ f_0 = \frac{2n-1}{4\tau} \quad (7)$$

n=positive integer, where f_0 is the carrier frequency.

III. RESULTS

Fig.8 shows the results of the dispersion monitoring scheme presented in Fig. 1, for three different wavelengths, when the bit rate is 40 Gbit/s

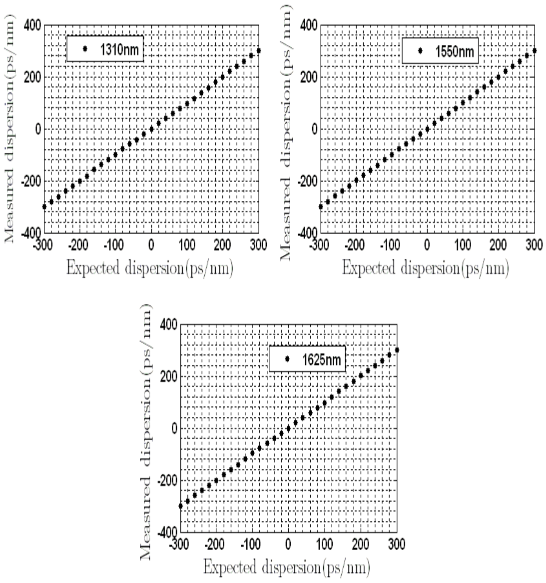

Fig. 8 Simulation results of the measured vs expected residual dispersion for three different wavelengths.

As can be seen the monitoring scheme matches very accurately the measured residual dispersion with the expected one.

Although not shown, this method can be used in different modulation formats, such as RZ, NRZ (both tested) and according to [1], in all modulation formats, with symmetrical spectrum (CSRZ, RZ-DPSK, CSRZ - DPSK, etc.). In these cases instead of measuring the magnitude of the AM pilot tone we measure the magnitude of the clock component f_c, at the constructive port of the DAF.

Table 1 shows that the method is multirate tuneable, matching very accurately the expected dispersion with the measured one, for different bit rate values. To vary the bit rate, we just need to adjust f_c in the Variable Dispersion Compensator (VDC) algorithm, as suggested in the flowchart of Fig.6.

To test the resolution of the monitoring scheme the following measuring conditions were used: bit rate equal to 40 Gbit/s, transmission wavelength equal to 1550 nm, an optical fibre of 20 km and a FBG tuneable dispersion compensator. The power of the laser was 0 dBm. The format used was RZ modulation.

Average sensitivity = (maximum AM pilot tone power - minimum AM pilot power)/ (T/2) ≈ 1 dB/ (ps/nm). This result demonstrates high sensitivity, which is important for high bit rates.

Table 1 Expected and measured values of residual dispersion for different bit rates

Bit Rate (GBit/s)	Expected dispersion (ps/nm)	Measured Dispersion (ps/nm)
1	180	185.6
3	180	191
5	180	179.12
8	180	179.64
10	180	178.06
15	180	179.12
20	180	179.12
25	180	179.6
30	180	179.12
35	180	179.12
40	180	179.64

IV. CONCLUSIONS

The proposed monitoring method, demonstrated a large monitoring window in the order of $\pm 300 ps/nm$, and for different wavelengths, at a bit rate of 40 Gbit/s. Larger monitoring windows are also possible. The method can be used with any modulation format with symmetrical spectrum. The monitoring method showed that it is multirate tunable, i.e., for different values of bit rates, the method continued to match expected and measured residual dispersion values. The method also showed high sensitivity.

V. ACKNOWLEDGMENTS

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