REAL TIME PMD COMPENSATION

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Abstract: We report on a novel technique to compensate for all-order polarization mode dispersion. By means of this technique, based on a suitable combination of phase modulation and group velocity dispersion, we recovered up to 60 ps of DGD affecting a 10 Gbit/s RZ data stream.

One of the major drawbacks in high bit-rate transmission systems is the presence of random birefringence of the fibres leading to polarization mode dispersion. New techniques of fibre fabrication permit to achieve low values of PMD, but this does not necessarily hold for the large amount of already installed fibers. For those the value of PMD may result increased with respect to that of new fibres either because of the phenomenon of stress relaxation in aged silica and because of the old fabrication techniques. In practice the transferring of the lab technology to the field is often limited by this problem.

Attempts to envisage PMD compensation techniques have been carried out [1-4]. Considering that the main difficulty arises from the time dependent stochastic nature of PMD. all the reported compensation devices are required to continuously feedback the input signal. Because of this reason these devices have a compensation rate that possibly does not account for relatively fast fibre DGD fluctuations. Moreover second order PMD is a further issue to be taken into account in the compensation technique. This contribution becomes increasingly important in high bit-rate transmission systems [5]. Means to compensate for 2nd order PMD have been reported, [3], but in the practical implementation are quite cumbersome.

The basic idea we propose in this work relies on a technique that independently of the input state of polarization substantially converts temporal fluctuations in frequency fluctuations. This mean, when used at the receiver, permits to restore the signal profile in the temporal domain leading therefore to a substantial opening of the electrical eye.

In order to illustrate the basics of the device let's assume an RZ modulation format whereas the single bit '1' is a gaussian pulse defined as

$$u(0,t) = e^{-\frac{(t-\tau_0)^2}{2T_0^2}} \qquad (1)$$

whose pulsewidth is $T_{fwhm} = 2\sqrt{\ln(2)}T_0$. The temporal offset τ_0 is a generic displacement due to a fluctuation, in the case of PMD we assume that the original pulse is split in two orthogonal components equally separated by τ_0 with respect to center of the time slot.

We suppose to apply a synchronous phase modulation to the incoming signal

$$m(t) = e^{i\alpha_m \cos(\Omega_m t)} \approx e^{iKt^2} \qquad (2)$$

that for the sake of simplicity has been expanded around the peak and $K = \frac{1}{2}\alpha_m \Omega_m^2$. Afterward the phase modulation we let the signal propagate through a span of dispersive fibre such that the total group delay at the end was $D = \beta_2 L$. It is possible to demonstrate that for

$$KD = -\tfrac{1}{2} \qquad (3)$$

the combination of a phase modulation followed by a dispersive element provides an output signal proportional to the Fourier transform of the input, $\tilde{u}(\Omega) = \Im[u(t)]$. The output signal reads

$$u(L,t) = \left(\frac{2\pi}{D}\right)^{\frac{1}{2}} e^{i(2K\tau_0^2 - \frac{\pi}{4})} e^{-i(\Omega_0 t - \phi)} \tilde{u}(0,\Omega) \qquad (4)$$

where the phase factor $\phi = Kt^2$ is the parabolic chirp induced by the phase modulator, and $\Omega_0 = 2K\tau_0$ that indicates conversion from a temporal offset τ_0 to a frequency offset Ω_0. The frequency offset is also the reason why the device is not readily usable in-line.

For the specific case of the RZ pulse defined in (1), eq.(3) becomes

$$u(L,t) = -\sqrt{4\pi}T_0 K e^{-i(\frac{\pi}{4} + K\tau_0^2)} e^{-iKt^2} e^{-i\Omega_0 t} e^{-2K^2 T_0^2 t^2} \qquad (5)$$

It is clear from (4) that the initial pulse displacement τ_0 is exactly compensated. Moreover the input pulse width is exactly restored too by setting $K = 1/(2T_0^2)$ and $|D| = T_0^2$.

To test the theory we performed a lab trial based on the experimental setup shown in Figure 1. A 10 GHz rep-rate source was able to deliver a train of 35 ps long pulses that was sent into a Mach-Zehnder modulator driven by a pattern generator operating at 10 Gbit/s. The data stream was then sent through a polarization controller and a PMD emulator with selectable value of DGD. The signal affected by DGD was then sent to the PMD compensator (PMDC) and then sent to the detection unit. The detail of the PMDC is shown in the inset b) of Figure 1. The 20 km long span of step-index fibre gave a delay $D = -400\ ps^2$, whereas the modulation amplitude was $\alpha_m = \pi V / V_\pi = 0.7$ thus giving $KD = -0.55$.

Figure 1 :. Experimental set-up for the simulation of PMD in a 10 Gbit/s RZ transmission system. The Mach-Zehnder modulator driven by a pattern generator provides a PRBS 10 Gbit/s stream. To emulate system PMD the RZ stream was sent to a programmable polarization controller and then to a DGD device with selectable delay. The emerging signal is sent trough the PMDC whose details are shown in (b)

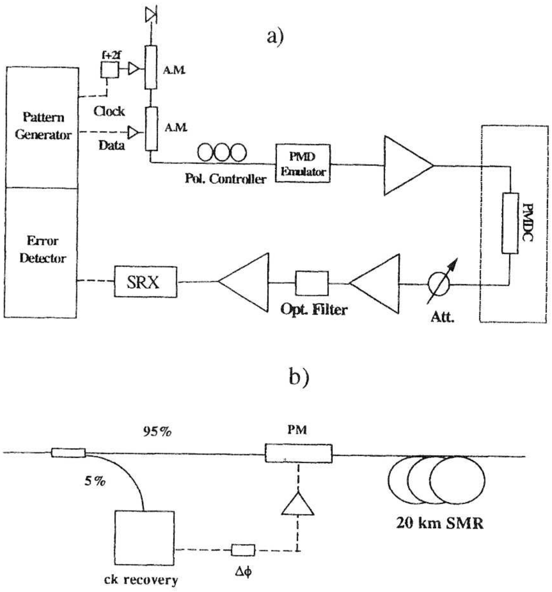
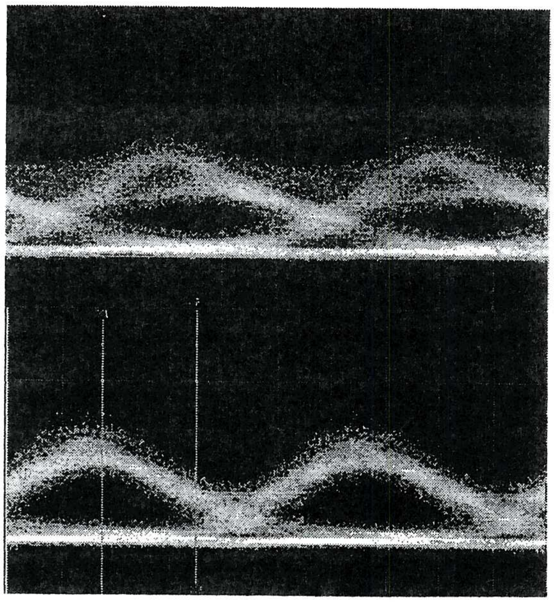


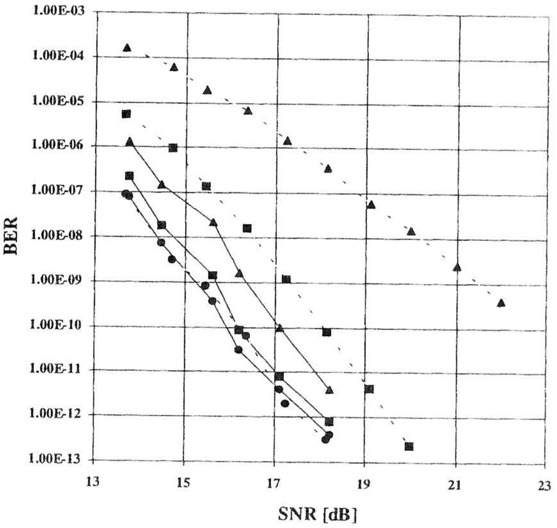
Figure 2 : Eye diagrams of the detected signal affected by 60 ps of DGD: upper trace with no PMDC, lower trace with PMDC included



As an example we report in Figure 2 a one minute persistency eye diagram measured with on without (upper trace), and with (lower trace) PMDC for an input DGD of 60 ps.

The performance of the device is reported in Figure 3. The BER was measured as a function of the signal to noise ratio at the receiver. In the figure we reported two sets of measurements concerning the case with (solid lines) and without (dashed lines) PMDC and each set refers respectively to DGD = 0 (circle), 40 ps (squares), 50 ps (triangles). It is worth noticing that at $BER = 10^{-9}$ the penalty due to 50 ps of DGD amounts to 6.1 dB, whereas with the inclusion of the PMDC the total penalty was lowered to 1.1 dB.

Figure 3 : 10 Gbit/s RZ bit error-rate measurements. The dashed and solid curves refer respectively to the cases without and with the inclusion of the PMDC. The different values of programmed delay are : DGD = 0 (circle), 40 ps (squares), 50 ps (triangles).



In conclusion we have demonstrated that large PMD compensation is achievable with a simple technique that exploits the property of the dispersive propagation of a linearly chirped signal to carry out the Fourier transform of the input signal itself. This process, intrinsically independent of higher order PMD, leads to the restoration of each pulse to the center of its own time slot. Moreover the experiment done with sinusoidal modualtion, i.e. not in the parabolic approximation as in eq.(1), demonstrated large operation tolerance.

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