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Post–Detection Electronic Compensation of Residual Dispersion for High-Speed WDM-Systems

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Abstract: We propose electronic decision feedback equalisation for compensation of residual dispersion. Improvement of dispersion tolerance for a simple equaliser with one coefficient is shown in the presence of fibre nonlinearity. Practical design rules for tuning the equaliser to various transmission environments are given.

Introduction:

In high-speed optically amplified transport networks based on WDM-technology, impairments of the optical channel, as dispersion, noise-enhancement and non-linear effects, impose transmission penalties and limitations. These systems are therefore necessarily dispersion compensated and require sophisticated link management. However, it is difficult to compensate for the chromatic dispersion in all of the WDM-channels by e.g. dispersion compensating fibre (DCF). Therefore channel-by-channel compensation may even be necessary [1]. Thus it would be very helpful if the receiver would show a reduced sensitivity against residual dispersion, or, more generally, could compensate for inter-symbol-interference in the received eye-pattern by electronic equalisation [2-6]. We investigate such post-detection equaliser schemes and present here results of a simple first order decision-feedback equaliser (DFE). We derive design rules and show performance improvements with respect to dispersion tolerance in the presence of fibre nonlinearity.

System:

In order to evaluate dispersion tolerance of an optical receiver with DFE we proceed as in Fig.1. Dispersion is accumulated to a total of D_{tot}=3400ps/nm along a standard single mode fibre (SSMF, dispersion parameter D=17ps/nm/km, loss a_{SSMF}=0.2dB/km) and then compensated for in a DCF-module (D=-85ps/nm/km, a_{DCF}=0.5dB/km). Various levels of input power to the SSMF are considered, so that self-phase-modulation occurs (non-linear coefficient γ=1.6(kmW)$^{-1}$), which is gradually reduced towards the end of the SSMF. The length of the DCF is varied in order to allow for a total residual dispersion in the range ±3400ps/nm. The 10-Gb/s receiver consists of a photodiode as a square-law detector, a low-pass filter (Butterworth 3rd order, $f_{cutoff,3dB}=7GHz$), a gain controlled amplifier (V) and the data decision (decision levels normalised to 1 and 0) with a DFE [7] with one feedback coefficient b only, which can be implemented in hardware at 10 Gb/s [6,8]. Since we are interested in dispersion tolerance, the total span-loss is compensated in one amplifier. The gain V of the amplifier keeps the normalised signal power at the subtracting point approximately constant which results in a constant decision threshold with a normalised value of 1/2.

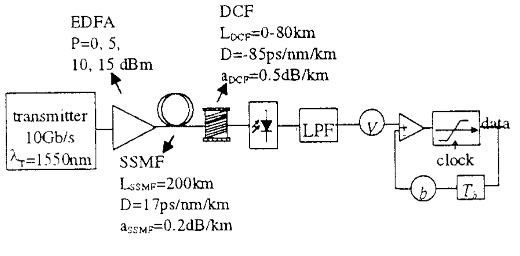

Fig. 1: Setup for evaluation of dispersion tolerance of receiver with electronic decision feedback (DFE). Feedback coefficient b, bit duration T_b

Results:

We measure by simulation the eye opening penalty (EOP) normalised to the back-to-back case. Dispersion tolerance is defined via a 1-dB EOP degradation. It is shown in Fig. 2 that the DFE can improve dispersion tolerance by at least 45% in the simple first order constellation. Our results confirm [9], that undercompensation is necessary for higher power levels. Results are shown for optimum feedback coefficient b and with and without optimum adjustment of the timing phase Δt. Coefficient b and gain V are simultaneously numerically optimised by minimising the mean square error (MSE) between the detected bits at the output and the signal at the input of the decision device. In order to get results independent from the gain V of the amplifier and the total span loss the feedback coefficent b is normalized to the product of both:

$$b_n = b / V \cdot 10^{(a_{SSMF} L_{SSMF} + a_{DCF} L_{DCF})/20} \qquad (1)$$

We found approximately a square law dependency of the normalized feedback coefficient b_n versus the total dispersion (Fig. 3), which can be approximated by the equation

$$b_{n,opt} = (c_{21}P + c_{20})D_{tot}^2 + (c_{11}P + c_{10})D_{tot} + c_{01}P + c_{00}, \qquad (2)$$

where P is the SSMF-input power value in mW and D_{tot} is the total dispersion value in ps/nm. The fitted parameters are c_{21}=3.70 10^{-9}, c_{20}=8.31 10^{-8}, c_{11}=-1.33 10^{-5}, c_{10}=7.29 10^{-6}, c_{01}=6.40 10^{-3} and c_{00}=-1.70 10^{-2}. This relation may be used as a design rule for DFE tuning in a reduced complexity solution as an alternative to an adaptive algorithm. For a hardware

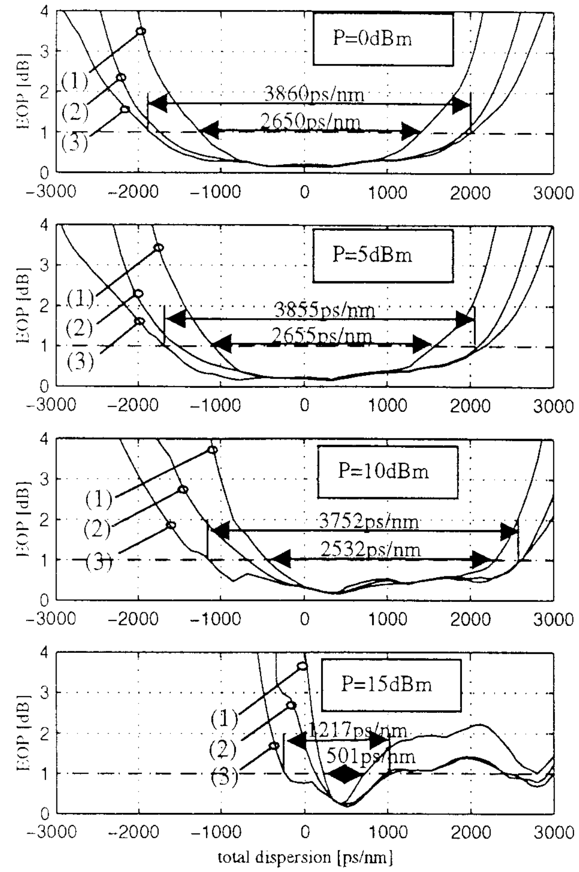

Fig. 2: eye opening penalty due to residual dispersion at 10Gb/s (1) without DFE, (2) DFE with fixed sampling time instant, (3) DFE with optimised sampling time instants

implementation it is important to notice, that for high optical power the sign of b_n becomes negative.
An additional parameter, which influences the performance is timing phase. In our simulation we have controlled the sampling time instant by monitoring the effective eye opening. Compared to the case of non equalisation, the sampling time instant has to be shifted slightly to earlier values. For Δt normalised to the bit duration T_b we found a weak dependency of D_{tot} (in ps/nm) which can be approximated by

$$\Delta t/Tb = -2.5\ 10^{-8}\ D_{tot2} \tag{3}$$

The approximation is independent of power P in the range D_{tot}>0 of interest.

Conclusion: It is demonstrated by simulation, that post-detection compensation with an electronic DFE of first order may improve dispersion tolerance by more than 45% for a wide range of practically used optical power-levels. We evaluated in eq.(1) and (2) practical design rules for optimum tuning of the DFE parameters.

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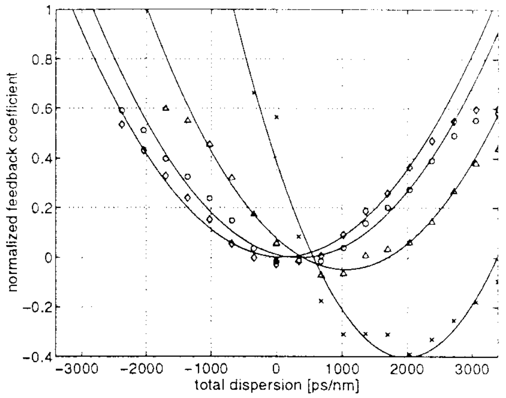

Fig. 3: Optimum normalised feedback coefficient b_n vs. residual dispersion D_{tot} for various input power levels P, the solid lines are parabolic fit curves.
◇ 0dBm, ○ 5dBm, △ 10dBm, × 15dBm

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