PERFORMANCE OF ELECTRONIC COMPENSATOR FOR CHROMATIC DISPERSION & SPM

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Abstract: We investigate nonlinear electronic equalisation for compensation of residual dispersion. The enhanced dispersion tolerance for a simple Decision-Feedback-Equaliser (DFE) and the further improvement in case of applying an additional feedforward filter is shown. Practical design rules for the DFE 1st order are given.

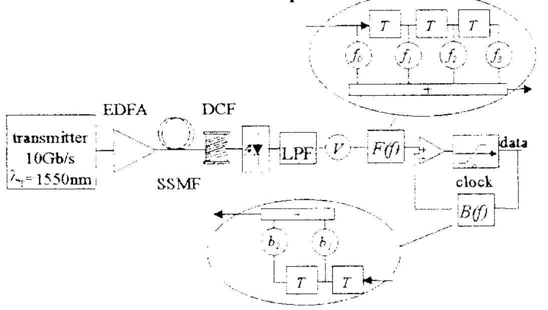
Introduction:

In high-speed optically amplified transport networks based on WDM-technology, it is difficult to compensate for the chromatic dispersion in all of the WDM-channels by e.g. dispersion compensating fibre (DCF). Thus it would be helpful if the receiver would show a reduced sensitivity against residual dispersion. Recently electronic equalisers have been realized in hardware by several groups /3-5/. We investigate such post-detection equaliser schemes /1,2/ and present here results of 1st and 2nd order decision-feedback equaliser (DFE) as well as the combination of a linear feedforward filter with a 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 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 (0dBm, 5dBm, 10dBm, 15dBm) to the SSMF are considered, so that self-phase-modulation (SPM) occurs (non-linear coefficient $\gamma=1.6(\mathrm{kmW})^{-1}$). 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) followed by a feedforward equaliser filter $F(f)$ and the data decision with feedback filter $B(f)$ /6/. As indicated in Fig.1 both filters are transversal filters with tap weights f_i, $i=0...3$ and b_i, $i=1,2$ and tap spacing T. If the performance of the DFE only shall be investigated the feedforward filter is omitted. The gain V of the amplifier keeps the normalized mean signal power at the input of $F(f)$ constant (automatic-gain-control).

Fig. 1: Setup for evaluation of dispersion tolerance of receiver with electronic Equalisers



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. The extension to two feedback coefficients results in a small further improvement. However applying an additional feedforward filter (4 taps, 100ps spacing) results in a more distinct dispersion tolerance.

The coefficients of the forward and feedback filter 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 the case of a DFE 1st order ($b_1=b$, $b_2=0$) without forward filter we will point out the evolution of the feedback coefficient b and the decision threshold in detail.

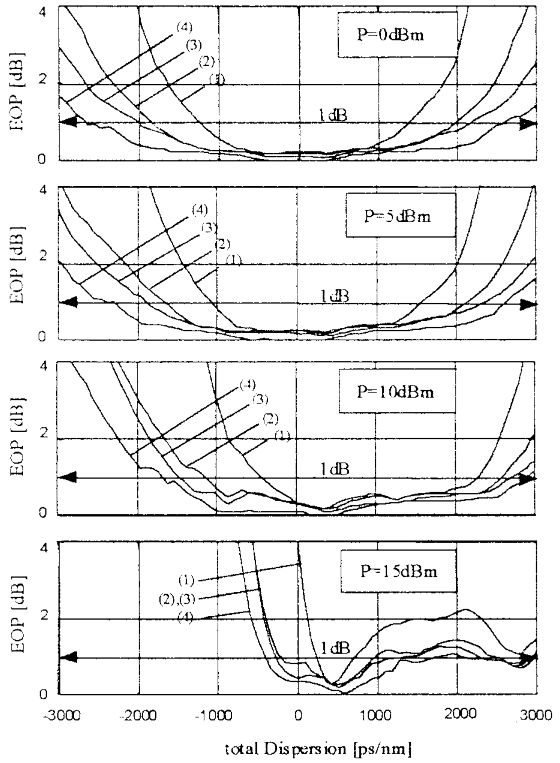
We found approximately a square law dependency of the feedback coefficient b versus the total dispersion (Fig. 3). Without equalisation ($b=0$) the center of the eye is due to the amplification at a value of 10^{-3} for all values of the total dispersion and all input power levels. b can be approximated by the equation

$$b=(c_{21}P+c_{20})D_{tot}^{\,2}+(c_{11}P+c_{10})D_{tot}+c_{01}P+c_{00}, \qquad (1)$$

where P is the SSMF-input power in mW and D_{tot} is the total dispersion in ps/nm. The fitted parameters are $c_{21}=3.70\ 10^{-9}$, $c_{20}=8.31\ 10^{-8}$, $c_{11}=-2.66\ 10^{-5}$, $c_{10}=1.46\ 10^{-5}$, $c_{01}=1.29\ 10^{-2}$ and $c_{00}=-3.39\ 10^{-2}$. This relation may be used as a design rule for DFE tuning in a reduced complexity solution as an alternative to an adaptive algorithm.

To understand the evolution of the decision threshold consider a detected data value of one. In this case the coefficient b is fed back to the subtracting point at the input of the decision device. Hence the mean signal high and low level at the input of the decision device decrease with an increasing value of b. Thus the decision threshold (center of eyediagram) has to decrease with increasing feedback coefficient. Fig.3 shows the decision threshold. A threshold value of one correlates to a feedback coefficient of zero (no equalisation). The evolution of the decision threshold can approximated by a parabolic function equal to Eq. (1)

Fig. 2: EOP due to residual dispersion and SPM at 10Gb/s (1) w/o equalization, (2) DFE 1st order, (3) DFE 2nd order, (4) feedforward filter followed by 1st order DFE



with the parameters: $c_{21}=-4.65\ 10^{-6}$, $c_{20}=-2.54\ 10^{-8}$, $c_{11}=1.96\ 10^{-2}$, $c_{10}=-4.64\ 10^{-5}$, $c_{01}=-7.10$, $c_{00}=1$.

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.

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. A second order DFE results in a slight improvement only, whereas improvement with an additional feedforward filter is significant We evaluated practical design rules for optimum tuning of the DFE parameters.

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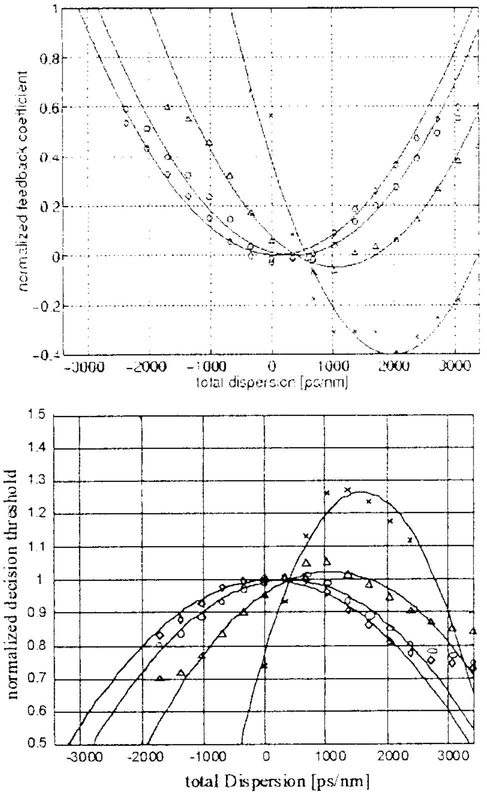
Fig. 3: DFE coefficient *b* (upper plot) & decision threshold (lower plot) vs. residual dispersion D_{tot} (both normalized to 10^{-3}) the solid lines are parabolic fit curves.
◊ 0dBm, ○ 5dBm, △ 10dBm, × 15dBm



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