Tunable Dispersion Compensation in a 40 Gb/s System using a Compact FIR Lattice Filter in SiON Technology

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Abstract *We present a tunable dispersion compensator for 40 Gb/s optical transmission systems, based on a Finite Impulse Response (FIR) lattice filter. The device has a Free Spectral Range (FSR) of approximately 100 GHz, low delay ripple and a wide tuning range from D = -120 ps/nm to +120 ps/nm. System experiments are presented for 40 Gb/s NRZ coded transmission.*

Introduction

In high bitrate optical transmission systems dispersion compensation is a critical aspect, as the dispersion tolerances will be smaller than the temporal dispersion fluctuations in the system, e.g. due to rerouting or temperature and power variations. Therefore, to compensate for these variations a tunable dispersion compensation is needed.

Actual integrated tunable dispersion compensators are based on Fiber Bragg Gratings (FBG), Finite Impulse Response (FIR) and Infinite Impulse Response (IIR) filters [1].

FBG devices offer a large tuning range and bandwidth, but are fixed to one wavelength and exhibit distortions due to group delay ripple. FIR and IIR filter have a periodic frequency response, tunable center wavelength and a large variability in compensating for distorting effects, such as dispersion, higher order dispersion, self-phase modulation (SPM) and polarization mode dispersion (PMD) [2-4]. As the frequency response is periodic, a single filter can equalize a number of WDM channels simultaneously by matching the FSR, the periodicity of the transfer function, to the channel grid. IIR allpass (AP) filters are based on ring resonators or etalons. The FSR is determined by the absolute path length of the feedback. For planar lightwave circuit (PLC) integrated ring resonators with a usable bandwidth of *50 GHz* or more, the radiation loss due to small ring radii gets significant, which leads to the loss of the AP characteristic and to strong intensity ripples.

PLC integrated FIR lattice filters can easily be designed for a large bandwidth of *100 GHz* or more as the device is a feed forward filter and the FSR is given by a differential path difference, and not by the absolute feedback path. Equalization is achieved by controlling the coupling ratios and the phase differences of the interfering signals, using variable couplers and tunable delay lines.

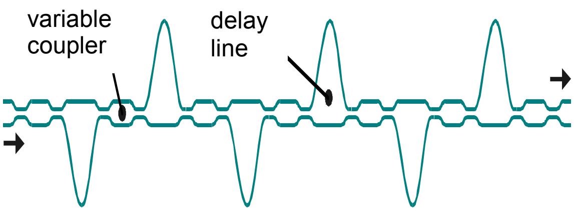

Fig.1: Six stage FIR-lattice filter layout

A six-stage tunable FIR-lattice filter of a FSR of approximately *100 GHz* with a dispersion tuning range of $\Delta D = 240$ *ps/nm* at a usable bandwidth of more than *60 GHz* is presented and demonstrated in system experiments at *40 Gb/s*. The device has been designed and produced by IBM, the system experiments have been performed at Siemens.

Device Layout and Fabrication

The schematic device layout of our FIR filter is shown in Figure 1. The FSR is determined by the optical path-length difference of the delay sections of the filter. For a target FSR of *100 GHz*, this length difference is about *2 mm*. The most efficient layout for a delay line is a folded structure. The entire device can then be designed with alternating delay lines, as indicated in Figure 1 [2]. The device was designed and fabricated using the IBM high-index-contrast SiON technology [6], using a large bending radius of *1mm*. The die size is $16 \times 12\ mm^2$.

System Test Results and Discussion

To demonstrate the functionality of the device, we first calculate the desired dispersion equalization values and then evaluate the resulting eye pattern and bit error rate in a system test at *40 Gb/s* NRZ transmission.

The device can be controlled using 13 heater currents, which determine the power cross coupling of the seven variable couplers and the phase settings of the 6 delay lines. The device is used here as a tunable dispersion equalizer, therefore the group delay response should be linear with low ripple over most of the FSR. The coefficients are calculated by approximating a given transfer function with a gradient algorithm. Figure 2 shows the measured linear group delay, corresponding to dispersion settings of *D = +100, +50, -50, -100 ps/nm*. The maximum ripple is below *1.5 ps*.

The system setup consists of a tunable laser source at *1550 nm*, which is externally modulated with a

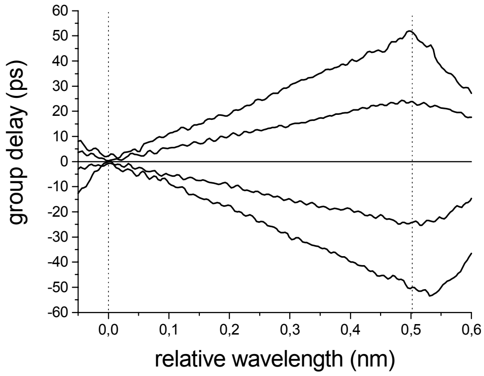

Fig.2: Measured group delay, compensation of dispersion values D = +100, +50, -50, -100 ps/nm

40 Gb/s NRZ signal. In order to evaluate the system performance of the tunable dispersion compensator, the filter is used to compensate for different fiber length with positive and negative dispersion. The launch power into the fiber is *P = 0 dBm* for a linear transmission. Due to birefringence of the waveguide, the input polarization has to be controlled. At the receiver the o/e conversion is done by a high current photo diode. Eye pattern and bit error rates (BER) are measured for *4* configurations: back to back, zero dispersion compensation ($D_0 = 0$ *ps/nm*), compensation of positive ($D_1 = +120$ *ps/nm*) and negative ($D_2 = -120$ *ps/nm*) residual dispersion, see Figure 3,4.

a.) In the back to back configuration the transmitter output is directly connected to the receiver input.

b.) For the zero dispersion configuration no fiber, but the filter is inserted and set to 0 ps/nm. There is no visible eye penalty and only a penalty of *0.1 dB* at a bit error rate of $BER = 10^{-10}$.

c.) In the case of positive residual dispersion, transmission fiber is inserted and $D_1 = +120$ *ps/nm* is compensated by the filter. The eye is nearly 100%

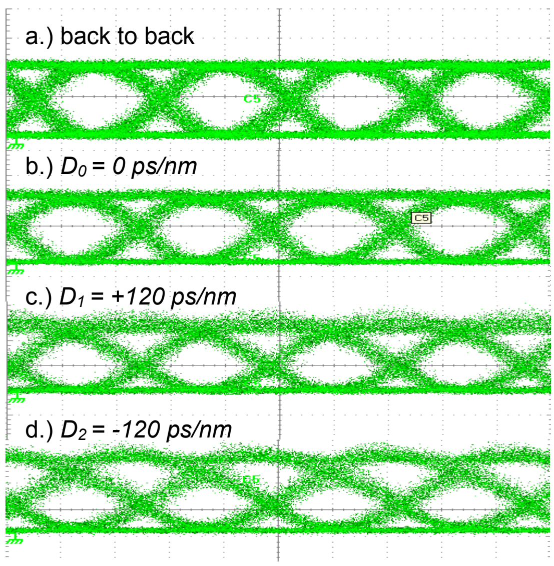

Fig.3: Measured eye pattern @ a.) back to back, compensation of b.) $D_0 = 0$ *ps/nm, c.)* $D_1 = +120$ *ps/nm, d.)* $D_2 = -120$ *ps/nm*

restored with a small sensitivity penalty well below *1 dB* at a $BER = 10^{-10}$.

d.) By inserting dispersion compensating fiber (DCF), a negative residual dispersion of $D_2 = -120$ *ps/nm* is realized and compensated by the filter. The eye restoration is slightly worse and there is an additional penalty of *0.1 dB*.

Compensating for dispersion values smaller than $D = \pm 120$ *ps/nm* lead to an even better system performance and lower penalties.

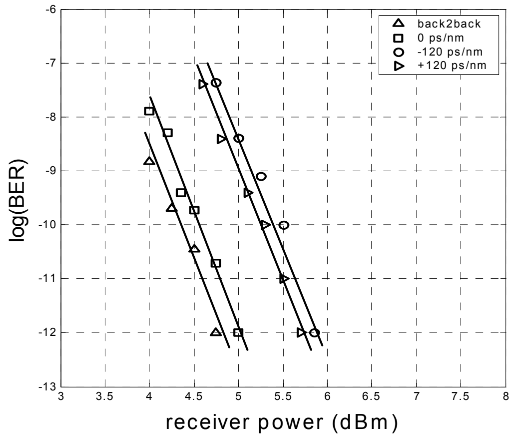

Fig.4: Measured Bit Error Rates @ back to back, compensation of $D_0 = 0$ *ps/nm,* $D_1 = +120$ *ps/nm,* $D_2 = -120$ *ps/nm*

The polarization dependency of the filter can be removed by reducing the birefringence in the delay arms. Alternatively polarization diversity schemes employing a polarization beam splitter and a circulator [4] or two devices, one for each orthogonal polarization can be used. The latter approach has the additional advantage that also PMD can be compensated by using a different transfer function for the orthogonal polarizations [7].

Conclusions

In system experiments it is demonstrated that a six stage FIR lattice filter is capable of compensating dispersion within a tuning range of $\Delta D = 240$ *ps/nm* at *40 Gb/s* NRZ transmission and a sensitivity penalty below *1 dB* compared to the back to back configuration. By increasing the number of stages, the filter performance and the tuning range can be further increased.

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