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Tunable all-fibre delay line filter for residual dispersion compensation in 40 Gbit/s systems

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A novel all-fibre tunable delay-line filter, with a simple structure based on two 3×3 fibre couplers and only one phase shifter is utilised for residual dispersion compensation in a 40 Gbit/s optical transmission system. In this experiment the dispersion tolerance of the receiver was successfully enhanced by 100 ps/nm.

Introduction: In optical networks with channel bit rates of 40 Gbit/s or higher chromatic dispersion is a severe limiting factor. The main part of the chromatic dispersion is usually compensated by dispersion compensating fibre, however a small amount of dispersion always remains due to, for example, rerouting or temperature variations. This residual dispersion has to be compensated adaptively to guarantee that the dispersion stays within the tolerant range of the receiver. For this purpose several approaches have been introduced. The most common solutions are tunable chirped fibre Bragg gratings [1] and optical delay line structures in planar- and bulk-optics. The capabilities of recursive [2, 3] and non-recursive [4, 5] delay line structures have been proven in system experiments. These components suffer from high loss due to fibre coupling and furthermore, planar devices are polarisation sensitive.

In this Letter, residual dispersion compensation with an all-fibre delay line filter is successfully demonstrated in 40 Gbit/s system experiments. The device is continuously tunable in the range of ± 50 ps/nm. Its major advantage is the simple structure and that the dispersion is controlled by changing only one parameter. To the best of our knowledge this is the first experiment utilising an all-fibre delay line filter for dispersion compensation.

Principle of operation: The device, shown in Fig. 1, consists of two 3×3 fibre couplers, connected in series with a set of delays in between (the middle and lower filter path have one and two unit delays, respectively). By selecting a unit delay of 10 ps, the free spectral range (FSR) of the device is set to approximately 100 GHz [6]. Owing to the non-recursive filter structure this optical filter is equivalent to a digital finite impulse response (FIR) filter of second order. In previous work it is shown that such filters require symmetric filter coefficients for linear group delay behaviour and that the group delay slope can be tuned by simply changing the phase of the middle coefficient [7]. Therefore the power splitting of the fibre couplers needs to be symmetric with 25, 50 and 25% of the input power in the upper, middle and lower path, respectively. Inserting a thermo-optic phase-shifter in the middle filter path enables tuning of the group delay slope.

Fig. 1 Schematic of optical delay line filter

The device was characterised from port 2 to port 5 using the phase-shift method [8] (modulation frequency 1 GHz). The results are shown in Fig. 2 for different group delay slopes. It can be seen that the group delay is linear with a low ripple (< 1 ps) in a bandwidth of 50 GHz around the centre of the period. Owing to the periodic spectrum of delay line filters, the adjacent channels show the same behaviour. By changing the input state of polarisation no significant changes in the transfer characteristic were observed. A detailed description of the properties and the production process of the device is given in [7].

System measurements: The measurements were carried out using an NRZ signal with a bitrate of 42.464 Gbit/s at a wavelength of 1555.75 nm. The dispersion tolerance of the receiver is approximately

110 ps/nm (bit error rate $< 10^{-10}$). To emulate the residual dispersion of a transmission system a switchable dispersion emulator was inserted between transmitter and receiver. For experiments the dispersion of the emulator was adjusted to 0 ps/nm, -105 ps/nm (negative dispersion) and $+105$ ps/nm (positive dispersion), enabling the filter to reduce the dispersion to the bounds of the tolerant region of the receiver.

Fig. 2 Measured amplitude and group delay for different slopes

a Group delay
b Group delay ripple
—■— 47 ps/nm
—*— 43 ps/nm
—○— 34 ps/nm
—◇— 30 ps/nm
—△— 16 ps/nm
—▽— 15 ps/nm

Fig. 3 displays the eye diagram measurements, where Fig. 3a shows the distorted eye for an uncompensated negative dispersion and Fig. 3c shows the corresponding compensated eye (filter dispersion value of $+50$ ps/nm). The eye diagram for an uncompensated positive dispersion can be seen in Fig. 3b and the same compensated (with -50 ps/nm filter dispersion) in Fig. 3d. In both cases the eye opening could be restored by the filter.

Fig. 3 Eye diagrams for compensated and uncompensated transmissions

a Negative dispersion (-105 ps/nm) uncompensated
b Positive dispersion ($+105$ ps/nm) uncompensated
c Negative dispersion (-105 ps/nm) compensated with $+50$ ps/nm
d Positive dispersion ($+105$ ps/nm) compensated with -50 ps/nm

Investigating the bit error rate (BER) against the receiver sensitivity (Fig. 4) shows that the device does not generate a significant penalty when it is inserted in the system with 0 ps/nm. By adding the appropriate amount of dispersion (selecting a filter dispersion value of -50 or $+50$ ps/nm, depending on the sign of the residual dispersion), the overall receiver residual dispersion tolerance range could be extended to 210 ps/nm with a maximum penalty of 1.2 dB.

Fig. 4 BER against receiver power for different filter dispersion values

- back-to-back measurement
- no dispersion with 0 ps/nm filter dispersion
- △— negative dispersion (−105 ps/nm) compensated with +50 ps/nm
- ▽— positive dispersion (+105 ps/nm) compensated with −50 ps/nm

The maximum insertion loss of the device was less than 3 dB. Its characteristics were found to be stable for several hours at room temperature without any temperature stabilisation.

Conclusion: A novel all-fibre delay line filter has been demonstrated that almost doubles the dispersion tolerance of a 40 Gbit/s NRZ system. The device's tunability enables adaptive compensation of residual dispersion. In further investigations the principle of operation has to be adapted to filters of higher order to increase the dispersion tuning range and the usable bandwidth.

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