Stretched fibre based dispersion compensating module for ultra high-speed telecommunication systems

C. Fortier, J. Fatome, S. Pitois, J.-P. Couvercelle, M.-L. Leonard, E. Pincemin and F. Reynaud

In this work, the potential efficiency of a low-loss, tunable second- and third-order dispersion compensating module based on a stretched optical fibre for ultra high-speed telecommunication systems is analysed. Experimental results at a repetition rate of 640 GHz show that precise dispersion compensation could be achieved in the range of ± 0.038 ps/nm by means of an 11.3 cm maximum stretching of a 48 m long dispersion compensating fibre.

Introduction: With the development of ultra-high-speed telecommunication systems, picosecond and even sub-picosecond pulses will have to be transmitted through optical fibres [1, 2]. At these ultra-fast repetition rates, the tolerance with respect to chromatic dispersion roughly decreases with the square of the bit rate and the performance of the system dramatically suffers from a non-perfect compensation of the in-line dispersion owing, for example, to the cumulative impairments of small sources of chromatic dispersion variations (such as fibre dispersion inhomogeneities or temperature dependence of fibre dispersion [3]). In this context, no doubt that the development of tunable, accurate and large bandwidth chromatic dispersion compensators will be a critical issue in order to dynamically adjust the cumulated dispersion of the line. Several experimental setups have proved their capacity to dynamically compensate for the chromatic dispersion in order to propagate very short pulses [2, 4, 5]. For example, by means of a spectral phase equaliser, 400 fs pulses have been transmitted over 10 km of fibre [4]. In [2], Nakazawa *et al.* transmitted 380 fs pulses at a bit rate of 1.28 Tbit/s over 70 km owing to a phase modulator based third- and fourth-order dispersion compensator. In another work, Eggleton *et al.* demonstrated tunable dispersion compensation at a bit rate of 160 Gbit/s thanks to a Bragg grating [5]. Unfortunately, the first method is only valid for single pulses, phase modulators are limited in bandwidth whereas Bragg gratings are also presently limited in bandwidth around 300 GHz and often suffer from a large group delay ripple [5]. In this Letter, the authors present a technique originating from the interferometer field where the replacement of classical mirror train delay lines by stretched optical fibre ones is proposed [6]. More precisely, we propose to extend this technique in order to develop a dispersion compensating module especially designed for ultra-high-speed telecommunication applications. Indeed, the stretched optical fibre based dispersion compensator has a quasi-unlimited bandwidth, is low loss, non-polarisation sensitive, accurately tunable and capable of compensating for both second- and third order chromatic dispersion. Experimental results at a repetition rate of 640 GHz show that precise dispersion compensation could be achieved around 1555 nm in the range of ± 0.038 ps/nm by means of a 11.3 cm maximum stretching of a 48 m long dispersion compensating fibre.

Experimental setup: Fig. 1 shows the experimental setup. The dispersion compensating module consists of a 320 m-long standard single-mode fibre (SMF) with dispersion $D = 17$ ps/nm · km, slope $S = 0.06$ ps/nm^2 · km and linear losses $\alpha = 0.2$ dB/km followed by a 48 m-long dispersion compensating fibre (DCF) from *ofs*, $D = -124.6$ ps/nm · km, $S = -0.41$ ps/nm^2 · km and $\alpha = 0.39$ dB/km at 1550 nm, which merely under-compensates for the total second- and third-order chromatic dispersion of the first SMF. The 48 m-long DCF fibre was wound and glued on a specific rubber rim, the diameter of which could be gradually increased by means of a large chuck as in a drill tool so as to increase the fibre length by uniformly stretching the DCF. To characterise the dispersion compensating module, a high quality, well-separated pulse train was first generated at a repetition rate of 640 GHz through the compression of a beat-signal [7, 8]. The initial beat-signal was generated by the superposition of two continuous waves (CW) delivered by two external-cavity lasers (ECL) and separated by 640 GHz around 1550 nm. The beat-signal was amplified by means of an erbium-doped fibre amplifier (EDFA) at an average power of 600 mW and then injected into a highly nonlinear fibre (HNLF) with the following parameters at 1550 nm: $D = 0.69$ ps/nm · km, $S = 0.0072$ ps/nm^2 · km, $\alpha = 0.72$ dB/km and $\gamma = 10.5$ W^{-1} km^{-1}. By means of the combined effects of Kerr nonlinearity and anomalous dispersion, the initial sinusoidal signal underwent a strong temporal compression into a well separated Gaussian pulse train having a full width at half maximum (FWHM) of 260 fs [7, 8]. The resulting pulse train was then injected into the dispersion compensating module and characterised thanks to a second-harmonic-generation autocorrelator. In parallel, the DCF stretching was measured with an accuracy of 20 μm owing to the time-flight measurement of 5 ps pulses emitted by a 22 MHz passively modelocked fibre laser, reflected on the DCF output connector and monitored by a 30 GHz bandwidth oscilloscope.

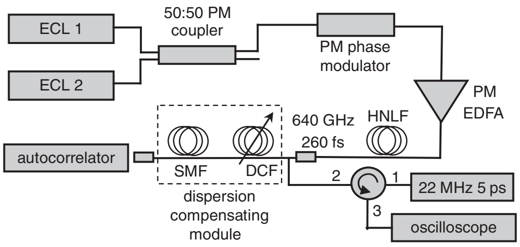

Fig. 1 *Experimental setup*

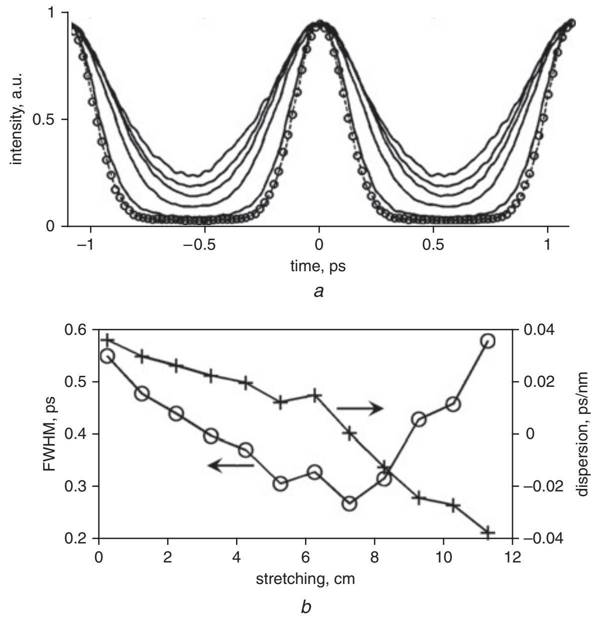

Fig. 2 Autocorrelation function and FWHM of 640 GHz pulse train

a Autocorrelation function of 640 GHz pulse train against DCF stretching From top to bottom: 11.3, 0.5, 1, 5, 8.8 and 7.3 cm (circle), dashed-line corresponds to initial pulse source
b FWHM of the 640 GHz pulse train against DCF stretching (circles); corresponding chromatic dispersion of module (crosses)

Experimental results: Fig. 2*a* represents the experimental autocorrelation function of the 640 GHz pulse train as a function of the DCF stretching. As can be seen, accurate chromatic dispersion compensation could be achieved thanks to the module. More precisely, perfect dispersion compensation was reached around 7.3 cm of stretching (circles) where pulses exactly recovered their initial shape (dashed-line). For a larger (or smaller) stretching, a broadening stage is observed due to the excess (or lack) of dispersion. Fig. 2*b* represents the corresponding FWHM (circles) as a function of the DCF stretching. The minimum FWHM, i.e the perfect compensation, is obtained for a measured DCF stretching of 7.3 cm. We have also deduced from the pulse broadening factor the corresponding chromatic dispersion induced by our module and undergone by the 640 GHz pulse train as a function of the DCF stretching. The results are presented in Fig. 2*b* (crosses) and show that a dispersion compensation could be achieved with an excellent accuracy in a range of ± 0.038 ps/nm thanks to a maximum DCF stretching of 11.3 cm (0.23% of elongation). Note that the dispersion curve of the module is asymmetric with respect to 0 ps/nm; we attributed this phenomenon to the slow decrease of the fibre core as a function of the stretching, which increases the local dispersion and then accelerates the compensation [3]. To measure the required applied force and to determine the potential maximum of stretching, we have performed a tension test on a 2 cm long sample of DCF. Results are shown in Fig. 3*a* where we have represented the elongation of the DCF sample as a function of the applied force. We can observe a linear behaviour the slope of which gives a Young's modulus of 83 GPa and a point of failure localised around 0.8% of elongation for an ultimate strength of almost 7.5 N corresponding to a stress of 600 MPa. Therefore, we estimate that the resulting maximum of stretching of our DCF module could reach 39 cm, which would correspond to a dispersion range of ± 0.2 ps/nm. Finally, we have measured the excess of losses (Fig. 3*b*, circles) and birefringence (Fig. 3*b*, stars) provided to the module by the DCF stretching. While the differential group delay (DGD) is merely constant as a function of the DCF stretching, we can observe that fibre losses increase slowly for stretching larger than 8 cm but still remain reasonable. Indeed, even though the applied stresses are shared along the DCF fibre length thanks to a uniform expansion of the spool diameter ensured by the chuck, we can attribute this behaviour to the increasing stress generated by a fibre overlap occurring during the winding stage.

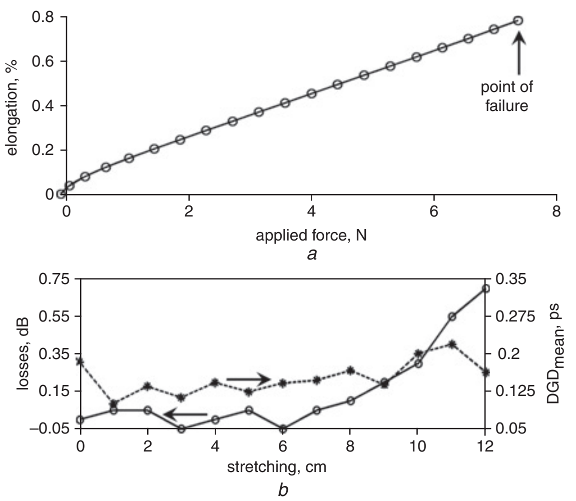

Fig. 3 Results of tension test, and excess of losses

a Results of tension test: Elongation of 2-cm long DCF sample against applied strength
b Excess of losses (circles) and DGD (stars) of module against DCF stretching

Conclusions: We have characterised a new type of dispersion compensation module based on a stretched optical fibre for ultra-high-speed telecommunication or laser applications. The present module is capable of precisely compensating for second-order dispersion, is tunable, low-loss, non-polarisation sensitive and with a quasi unlimited bandwidth. Experimental results at a repetition rate of 640 GHz show that precise dispersion compensation could be achieved in the range of ± 0.038 ps/nm by means of a 11.3 cm maximum stretching of a 48 m long dispersion compensating fibre.

7 May 2008
Electronics Letters online no: 20081279
doi: 10.1049/el:20081279

C. Fortier, J. Fatome and S. Pitois (*Institut Carnot de Bourgogne (ICB), UMR-CNRS 5209/Université de Bourgogne, 9 av. Alain Savary, Dijon 21078, France*)

E-mail: julien.fatome@u-bourgogne.fr

J.-P. Couvercelle (*Institut de Chimie Moléculaire de l'Université de Bourgogne (ICMUB), UMR-CNRS 5260/Université de Bourgogne, 9 av. Alain Savary, Dijon 21078, France*)

M.-L. Leonard (*Ecole Supérieure d'Ingénieurs de REcherche en Matériaux (ESIREM)/Université de Bourgogne, 9 av. Alain Savary, Dijon 21078, France*)

E. Pincemin (*France Telecom, Research and Development Division, Technopôle Anticipa, 2 av. Pierre Marzin, Lannion, Cedex 22307, France*)

F. Reynaud (*Xlim UMR-CNRS 6172, Dept Photonique/IRO, 123 rue A. Thomas, Limoges 87060, France*)

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