Overall Polarization Dispersion after Propagation through Different Fibres

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Introduction

Polarization dispersion is one of the effect which can give rise to data rate limitation. An actual optical link can be installed using different appended fibres, manufactured by different producers, processing techniques or batches. Knowing the polarization dispersion of each individual fibres, it could be difficult to forecast the overall dispersion of such an heterogeneous link. Fortunately recent models make the prediction of the global polarization dispersion possible.

In this contribution we report an experimental verification of this model using two different methods, so that the predicted dispersion of two appended non-similar fibres could be compared with actual measurements.

Theoretical background

The evolution of the state of polarization along a standard single mode fibre is stochastic because such a fibre shows a nearly perfect polarization degeneracy and thus strong mode couplings can occur. These couplings are due to environmental causes and fluctuates owing to mechanical stresses relaxations and temperature variations. Thus the actual output state of polarization cannot be anticipated and randomly varies on a slow time scale.

Polarization dispersion is therefore a random quantity and the retardation between polarization modes can be conveniently modelized by a Gaussian stochastic process, so that polarization dispersion is described by a Maxwell probability density function [1]. Thus the only way to characterize polarization dispersion of a fibre is to determine the parameters of the probability density function. The Maxwell distribution depends on one single parameter σ that fully describes the average expected pulse broadening.

When the light successively propagates throughout N different fibres the polarization states undergoes successive random couplings due to the independent Gaussian processes in each fibre. The overall effect is mathematically described by the convolution of the individual probability density functions of each fibre (variance σ_i^2). The resulting process remains Gaussian with a resulting variance given by

$$\sigma_{tot}^2 = \sum_{i=1}^{N} \sigma_i^2$$

Hence the individual contributions to pulse broadening add *quadratically*, as could be anticipated from stochastic processes.

Experimental results

The experimental check of this quadratical relationship has been achieved using two different methods: the interferometric loop (or Sagnac) configuration [2] and the Michelson interferometer [3]. The principles of these methods are described in another contribution at this conference [4]. These techniques are particularly suitable for such an experimental check, because they are the only methods to our knowledge that yield the dispersion probability density function and therefore give a valuable statistical information. Polarization dispersion of different fibres can thus be correctly compared.

First the polarization dispersion of 4 individual standard single mode fibres showing different σ_i's has been measured. These fibres were chosen owing to their

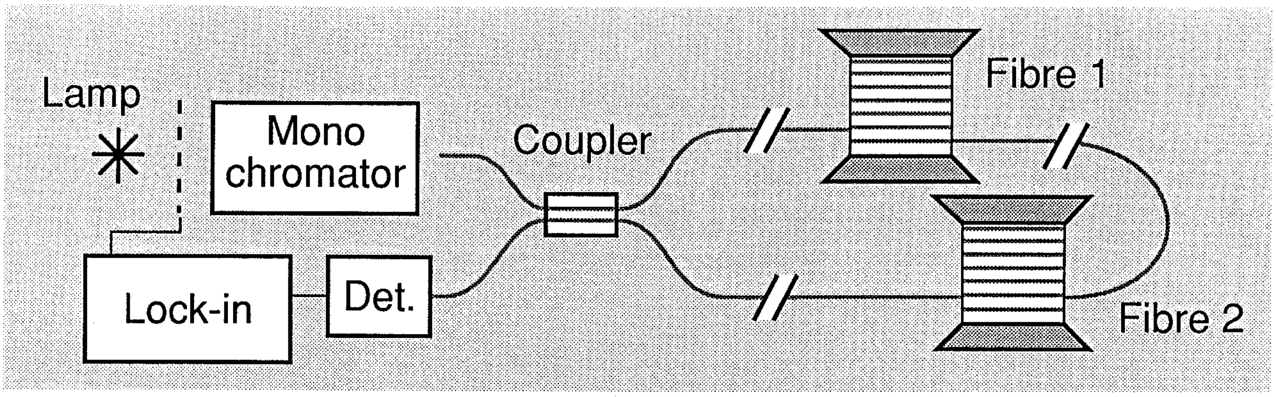

Fig. 1 Experimental configuration of the set-up using the Sagnac method for the measurement of two appended fibres.

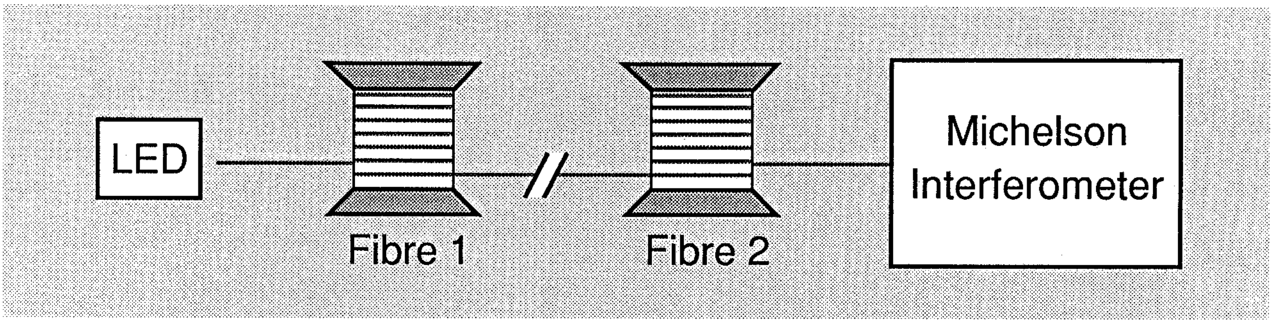

Fig. 2 Experimental configuration of the set-up using the Michelson method for the measurement of two appended fibres.

different core geometry: fibre I and II are depressed-cladded, fibre III and IV are matched-cladded, with a $7 \cdot 10^{-3}$ and $5 \cdot 10^{-3}$ index difference respectively. Fibres I and II were manufactured using distinct deposition processes.

Then the concatenation effect is evaluated by measuring the polarization dispersion of any combination of two appended fibres, as shown in Fig.1 and 2 for each method respectively.

Measurements performed over two appended fibres appear identical to those over one fibre, that is, a Gaussian function fits the experimental points as well, as shown in Fig.3 and 4 for each method. This is a first qualitative confirmation of the consistency of the model, the Gaussian nature of the polarization delay being clearly conserved.

Results of every combination of two appended fibres obtained using the interferometric loop configuration are shown in Table 1. The measured polarization dispersions of each individual fibre are on the diagonal in black boxes. The upper part of the table contains the predicted values calculated using the quadratic law and the lower part the corresponding experimental measurements. Table 2 shows the corresponding results obtained using the Michelson configuration. Some experimental values miss because the difference between the overall dispersion and the dispersion of fibre I is well within the experimental accuracy of 10%. Such measurements would therefore have no statistical significance.

These measurements show a fairly good agreement with the expected quadratic relationship and minor discrepancies are observed for the two methods, that are within the experimental accuracy. An unexplained different polarization dispersion is observed for fibre I comparing the two methods, but measurements performed using the same method are consistent.

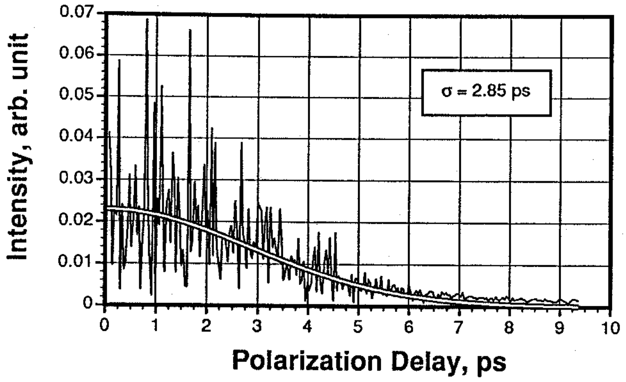

Fig. 3 Interference intensity versus delay after propagation throughout fibre 1 and fibre 3, measured using the Sagnac method, with numerical fit.

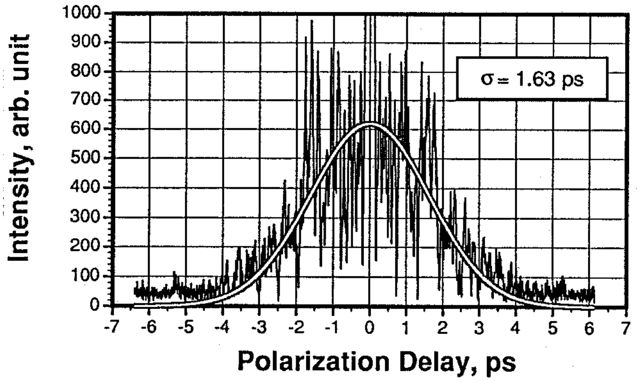

Fig. 4 Interference intensity versus delay after propagation throughout fibre 1 and fibre 3, measured using the Michelson method, with numerical fit.

	FIBRE				
	I	II	III	IV	CALCULATED
I	2.63	2.64	2.73	2.64	
II		0.21	0.77	0.32	
III	2.85	0.78	0.74	0.78	
IV		0.32	0.77	0.24	
MEASURED					

Table 1 :Comparative results of calculated and measured polarization dispersion of two appended fibres using the Sagnac method. Diagonal values are measured polarization dispersion of individual fibres, upper and lower values are calculated and experimental results, respectively.

	FIBRE				
	I	II	III	IV	CALCULATED
I	1.44	1.46	1.61	1.45	
II		0.21	0.74	0.27	
III	1.62	0.81	0.71	0.73	
IV		0.31	0.74	0.17	
MEASURED					

Table 2 Same comparative results using the Michelson method.

Conclusion

An experimental check of the quadratic summation of polarization dispersion in concatenated fibres has been successfully performed. This dispersion is therefore expected to grow as the square root of the propagation distance. As measurements performed throughout kilometer-length fibres show polarization dispersion in the picosecond range, a 100-km optical link is expected to have a only ten-fold increase of this figure, that is, in the tens of picosecond. This would be surely for ordinary links much smaller than the pulse broadening induced by chromatic dispersion, which grows linearly with distance.

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References

1. F. Curti, B. Daino, G. de Marchis, F. Matera, "Statistical Treatment of the Evolution of the Principal States of Polarization Dispersion in Single-Mode Fibers", IEEE J. Lightwave Techn., LT-8 (1990), pp.1162-1166.
2. L. Thévenaz, Ph. Robert, "Simple Method for Polarization Dispersion Measurements in Long Single-Mode Fibres", Proceedings ECOC'90, Amsterdam (1990), Vol.I, pp.581-584.
3. N. Gisin, J.-P. von der Weid, J.-P. Pellaux, "Polarization Mode Dispersion of Short and Long Single-Mode Fibers", IEEE J. Lightwave Techn., LT-9 (1991), in press.
4. N. Gisin, J.-P. Pellaux, L. Thévenaz, G. Bernasconi, R. Passy, "Interferometry for Polarization Mode Dispersion Measurements in Single Mode Fibres", Proceedings EFOC/LAN'91, former contribution.