Simple Method for Polarization Dispersion Measurements in Long Single-Mode Fibres

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Abstract: A novel method of polarization dispersion measurements using an interferometric loop is presented. It can be carried out using a particularly simple set-up and provides a representation of the probability distribution of the polarization dispersion.

Introduction

The study of polarization dispersion in standard single-mode fibres takes on a growing importance, because the delay between polarization modes causes pulse broadening and may become predominant in multigigabit long-span optical links. The combined effects of weak birefringence and fluctuating mode coupling result in a stochastic behaviour of the polarization dispersion and of the output polarization state. The so-called principal states, a particular set of orthogonal polarization states, experience the greatest difference in propagation time and are therefore very convenient for the description of polarization dispersion [1]. Recent contributions use the properties of these states to demonstrate that the evolution of polarization is quite similar to a random walk and the probability density function of the fluctuating polarization dispersion can therefore be described by a Gaussian-like distribution [2,3].

Several results have been reported so far on the measurement of polarization dispersion in long single-mode fibres, mainly using a technique analysing pathes over the Poincaré sphere [4,5]. This technique requires a high control of the laser source wavelength and the determination of the output polarization state using analyzing elements. Measurements without using any polarizing element can be performed by an interferometric technique [6], which is of little use for the study of random coupling, because it remains restricted to meter-length samples. In this contribution we present a novel method which allows the measurement of polarization dispersion in long single-mode fibres using a particularly simple set-up, without polarizing elements or retardation plates. Furthermore it makes the evaluation of the probability density function of polarization delay possible.

Basic principles

A schematic diagram of the experimental set-up is shown in Fig.1. It simply consists of a chopped white-light source spectrally filtered by a monochromator, a wavelength-independent single-mode

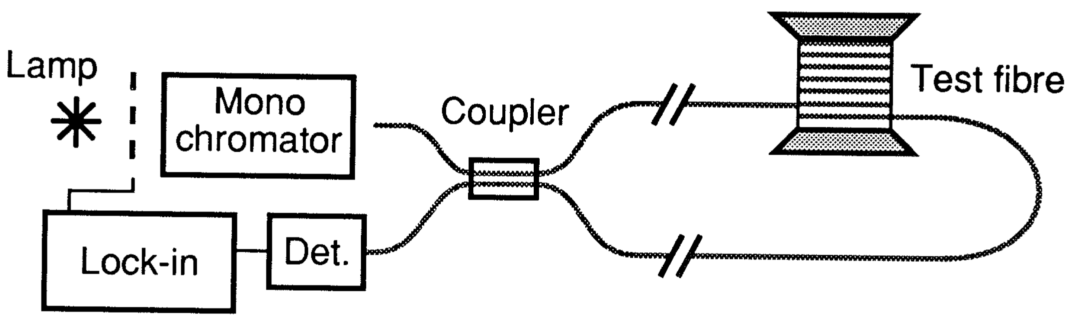

Fig.1 Schematic diagram of the experimental set-up.

coupler, the test fibre, a detector and a lock-in amplifier. The principle of operation is based upon the use of an interferometric loop (or "Sagnac interferometer"), which enables the two counterpropagating lightwaves throughout the test fibre to interfere for any fibre length and any source coherence length. When the test fibre is strictly single-moded (i.e. *one* transverse mode and *one* polarization mode) the optical pathes are also strictly equal for the two waves and the phase shifts experienced by the lightwaves in the coupler give only rise to destructive interferences, that is, no light is transmitted in the output fibre. But when the fibre is bimodal (i.e. *one* transverse mode and *two* polarization modes) non-destructive interferences may be observed when the following condition is fulfilled: principal states of opposite propagating directions through the test fibre are not parallel at the output fibre ends (i.e. are not represented by the same point on the Poincaré sphere). This condition is unlikely to occur, so that all situations of contrast are observed, depending on the relative orientation of the principal states at each end of the fiber. This orientation is unpredictable and is not constant over the spectrum (second order effect), so that the contrast slowly variesin a random way. A perfectly equal intensity can be launched into the two principal states using *unpolarized* light for improved contrast.

Now, when the source spectrum is scanned, the delay between the principal states gives rise to different phase differences between the interfering counterpropagating waves for different wavelengths, resulting in a succession of constructive and destructive interferences when the wavelength is incremented. The rate of succession of interferences when the wavelength is varied is therefore directly related to polarization dispersion.

Results

Fig.2 shows the detected intensity as a function of wavelength using this set-up for two different standard single-mode fibres. The succession of interferences is clearly observed. But the random evolution versus wavelength of principal states and of their delay causes the interference succession rate to fluctuate, clearly showing the stochastic nature of polarization dispersion in such a situation. In fact, different wavelengths result in different magnitudes of coupling constants between polarizations, a spectral scan performs something similar to an ensemble average and should therefore be equivalent to the slow random time variation of the polarization states behaviour at a given wavelength. This assumption holds if the residual birefringence is roughly constant over the investigated spectral range, which has been previously observed when the birefringence is stress-induced [7].

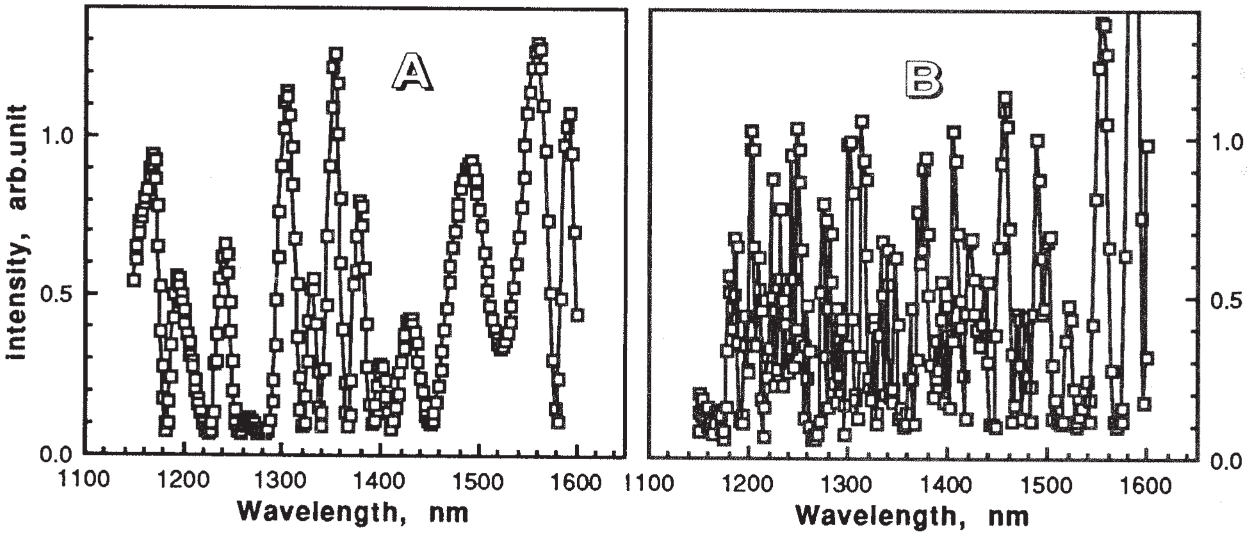

Fig.2 Detected intensity at the interferometric loop output for two different 3.5-km standard single-mode fibres.

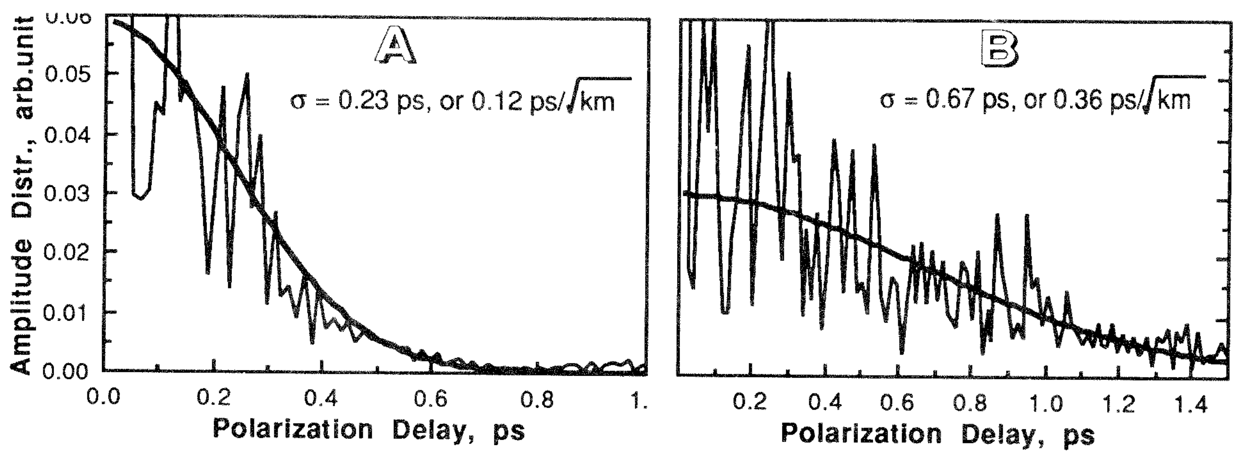

Fig.3 Fourier transform of the detected intensities shown in Fig.2, representing the distribution of polarization delay, and corresponding Gaussian fit with its standard deviation.

As mentioned above the succession rate of interferences with increasing wavelength is directly related to polarization dispersion, so that a Fourier transform performed over the detected intensities as a function of the optical frequency yields a representation of the probability density function of the polarization delays. The result of such a transform is shown in Fig.3. The stochastic nature of the delay is confirmed and the numerical fitting shows that the observed distribution is compatible with a Gaussian function. On the other hand a measurement on a short sample (3m), for which mode coupling is negligible, shows a regular succession of interferences and therefore the absence of a stochastic behaviour, as shown in Fig.4.

The minimum observable delay is limited by the spread of the investigated spectral range, because at least one interference succession must be measured, that is:

$$\delta\tau > \frac{\lambda_{max}\,\lambda_{min}}{c\,(\lambda_{max} - \lambda_{min})}$$

where λ_{min}, λ_{max} are the lower and upper bounds of the investigated spectrum, respectively. On the other hand the maximum observable delay is bounded by the source spectral width, because it must

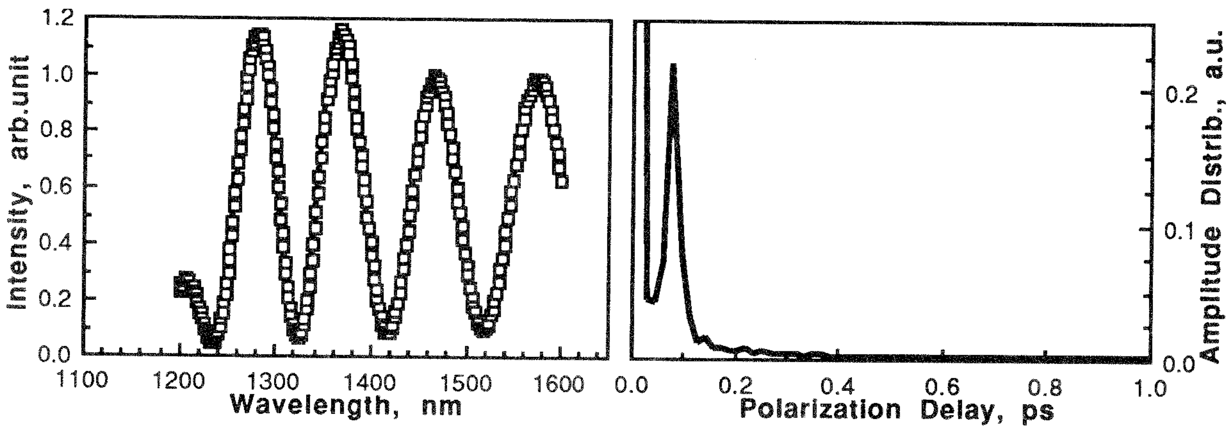

Fig.4 Detected intensity at the interferometric loop output for a 3-m sample of standard single-mode fibre showing no polarization fluctuation, and corresponding Fourier transform which reduces to a single peak in this case.

remain shorter than the coherence time in order to observe interferences. Hence

$$\delta\tau < \frac{\lambda^2}{c\,\Delta\lambda}$$

where $\Delta\lambda$ is the spectral width and λ the center wavelength. When this bound is reached, the interference contrast becomes very poor and the measurement can therefore at once be discarded.

With our set-up (λ_{min}=1000nm, λ_{max}=1700nm, $\Delta\lambda$=4nm) the absolute measurable delay is bounded this way:

$$0.008 \text{ ps} < \delta\tau < 1.4 \text{ ps}$$

Conclusion

This novel method of measuring polarization dispersion in long single-mode fibres differs from other techniques by its simplicity and easy handling. Furthermore it enables a straightforward evaluation of the statistical properties of the polarization delay of a given fibre. This method promises to become an important tool for the investigation of polarization properties in single-mode fibres and other guided-wave optical devices.

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