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Measuring the Chromatic Dispersion of Single Mode Fibres

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Abstract The principal techniques for chromatic dispersion measurements are described with special focus on the interferometric methods. The techniques are compared with respect to their results, advantages and limitations, and the influence of birefringence effects in chromatic dispersion measurements is evaluated.

1. INTRODUCTION

Pulse broadening in single mode fibres occurs because the laser sources radiate a spectrum of wavelengths, which propagate with different group velocities due to chromatic dispersion. This broadening of the input pulse will limit the minimum time slot between successive input pulses, or the highest bit rate which can be attained without significant intersymbol interference in a Pulse Code Modulation (PCM) transmission system. Chromatic dispersion is therefore a fundamental parameter which must be specified in single mode-high bit rate transmission systems. A number of papers have treated this subject either theoretically[1,2] or from the experimental point of view[3].

In this work we will discuss the origins and control of chromatic dispersion in single mode fibres and compare different techniques which are employed in chromatic dispersion measurement specially focusing on the interferometric methods. Finally, we will comment on the birefringence in single mode fibres and its influence in the different techniques.

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2. GROUP DELAY AND PULSE BROADENING

As a simple illustration, consider an input light pulse composed of two wavelenghts λ_1, and λ_2 (e.g. two longitudinal modes of the injection laser) launched in a single mode fibre as in fig.1a. Although simultaneously launched the two wavelenghts will propagate along the fibre with different group velocities and reach the detector at different times τ_1 and τ_2. This time spreading of the initial pulse is proportional to the length L of the fibre, and depends on the difference between the two wavelenghts λ_1 and λ_2. The chromatic dispersion of the fibre is defined as the time lag per unit length and spectral width between two simultaneous input pulses of close wavelenghts λ_1 and λ_2

$$D = \frac{1}{L}\frac{\tau_2-\tau_1}{\lambda_2-\lambda_1} = \frac{1}{L}\frac{d\tau}{d\lambda} \tag{1}$$

For polychromatic sources, such as multi-longitudinal mode semi-conductor lasers, the natural spectral width is much greater than the modulation bandwidth. This means that the light spectrum is unaflected by the modulation, and the power input can be written as

$$P_i(t) = \int p(\lambda)f(t)d\lambda \tag{2}$$

where $f(t)$ is the time function describing the modulation.

The output power after propagation along a length L of fiber will be

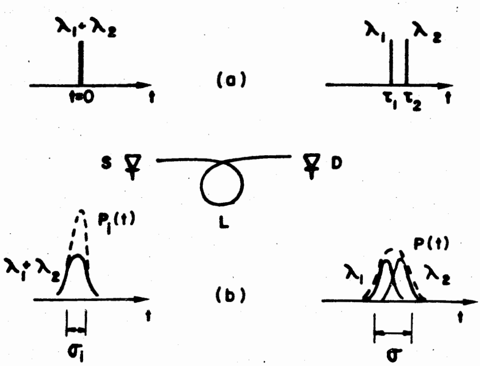

Fig.1 - Polichromatic pulse propagation in a single mode fibre.

$$P(t) = \int p(\lambda) f(t-\tau(\lambda)) d\lambda \qquad (3)$$

where $f(t)$ is the propagation time corresponding to the wavelength λ as shown in fig.1b.

One can easily see that if $\tau(\lambda)$ is a strongly varying function of λ, the initial pulse will be correspondingly distorted. As an example, consider a gaussian light pulse with rms width σ_i emitted from a source with a gaussian spectrum centered at λ_0 with spectral width $\Delta\lambda \ll \lambda_0$, launched into a fibre of length L. The rms width of the emerging pulse will be given by[2]

$$\sigma^2 = \sigma_i^2 + [D(\lambda_0) L \Delta\lambda]^2 + \frac{1}{2} [D'(\lambda_0) (L\Delta\lambda)^2]^2 \qquad (4)$$

Where $D(\lambda_0)$ and $D'(\lambda_0)$ are respectively the dispersion and the slope of the dispersion curve at λ_0. The last term in eq.(4) can actually be neglected unless $D(\lambda_0) \sim 0$. Taking typical numerical values for a single mode fibre at 1300nm, $D(\lambda_0) \sim 2$ps/nmkm $D'(\lambda_0) \sim 0.08$ ps/nmkm $\Delta\lambda = 4$nm and $\sigma_i = 100$ps we get a $\sim$ 200ps width pulse after 20km of fibre. The limit bit rate which can be transmitted in these conditions would then be $BR = 1/4\sigma \sim 1.25$Gb/s [2].

Of course, if the input pulse width could be neglected, these figures would give $BR = 1.55$Bg/s over the 20km fibre. Correspondingly, the length of this fibre which could support a 560 Mb/s transmission with 4nm spectral width would be ~ 55km.

This simple example illustrates the impact of chromatic dispersion on single mode transmission systems. Transmission bandwidths can be strongly increased by reducing the spectral width of the source and carefully tuning its wavelength to the zero of the chromatic dispersion of the fibre. The dependence of the bandwidth on the wavelength and spectral width of the source a typical fibre with zero dispersion at $\lambda = 1.3\mu m$ is shown in fig.2. Notice, however, that the tuning of the wavelength to the best performance of the fibre brings up severe restrictions on the characteristics of the fibres and sources to be used. A standardization which is generally imposed is that the fibre must have a chromatic dispersion between ±5 ps/nmkm in the spectral range between 1275nm and 1325nm.

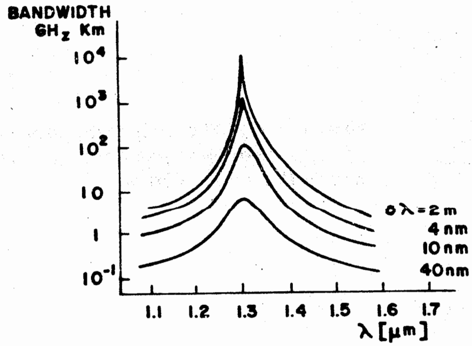

Fig.2 - Bandwidth of a typical single mode fibre as a function of the wavelength and spectral width of the source.

3. INDEX PROFILE AND CHROMATIC DISPERSION CONTROL

Chromatic dispersion appears because the propagation constant is a non linear function of ω:

$$\beta(\omega) = k\sqrt{n_2^2 - b(n_1^2 - n_2^2)}$$

where k is the free space propagation constant, ω is the angular frequency of the ligth, n_1 and n_2 are respectively the frequency dependent refractive indexes of the core and cladding. The parameter $b(\omega)$ is the normalized propagation constant, and depends on the frequency ω and the mode field distribution. The group velocity, given by $d\omega/d\beta$ is therefore frequency dependent, giving rise to chromatic dispersion.

The dependence of the propagation constant on the wavelength is schematically represented in fig.3. The upper and lower curves represent respectively the refractive indexes of the core and cladding material, and their wavelength dependence gives rise to the so-called material dispersion. In the range of small wavelength, the mode field is mostly confined to the core region so that $b \sim 1$ and the effective refractive index is close to n_1. In the range of large wavelengths the mode field is spread out over the cladding so that $b \sim 0$ and the effective index close to the cladding index n_2. The transition from n_1 to n_2 gives rise to the so-called waveguide dispersion, which can be controled for special effects by careful design of the index profile. These two main contributions to the total chromatic dispersion are shown in fig.4

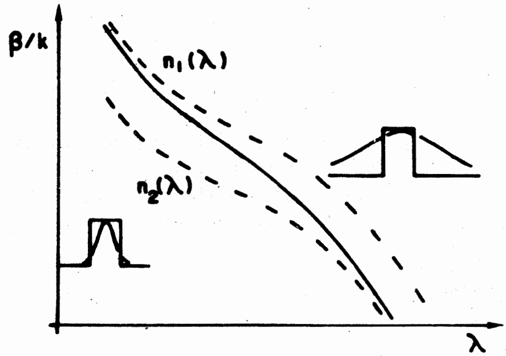

Fig.3 - Wavelength dependence of the propagation constant in a single mode fibre.

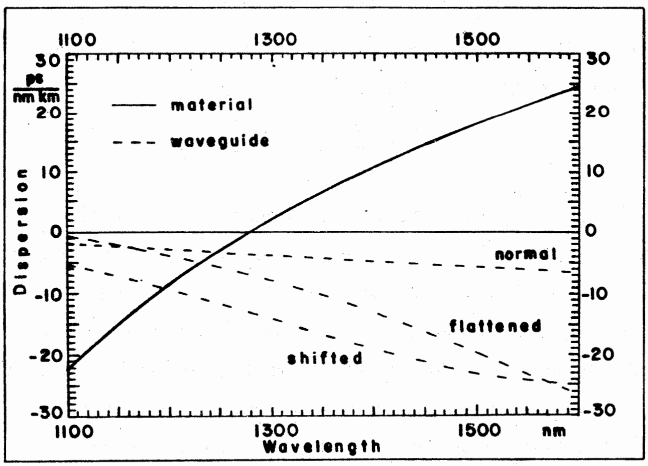

Fig.4 - Material and waveguide contributions to the chromatic dispersion of normal, dispersion shifted or dispersion flattened single mode fibres.

for three types of single mode fibres; the *normal* fibres, the *dispersion shifted* and *dispersion flattened* fibres. These contributions were calculated by numeric solutions of the scalar wave equation for an arbitrary index profile.

The delay spectrum and chromatic dispersion of a typical *normal* step index fibre is shown in fig.5 as measured with the interferometric technique. The waveguide dispersion can be increased by increasing the index step Δn as in fig. 6, but more complicated profile such

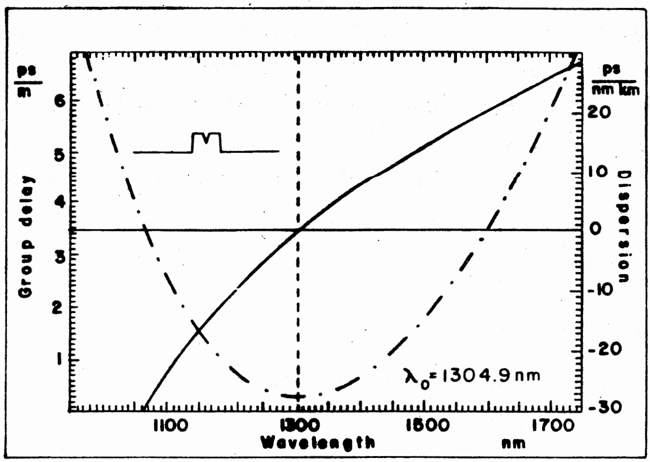

Fig.5 - Group delay and chromatic dispersion of a standard step index single mode fibre designed for the 1.3μm transmission window.

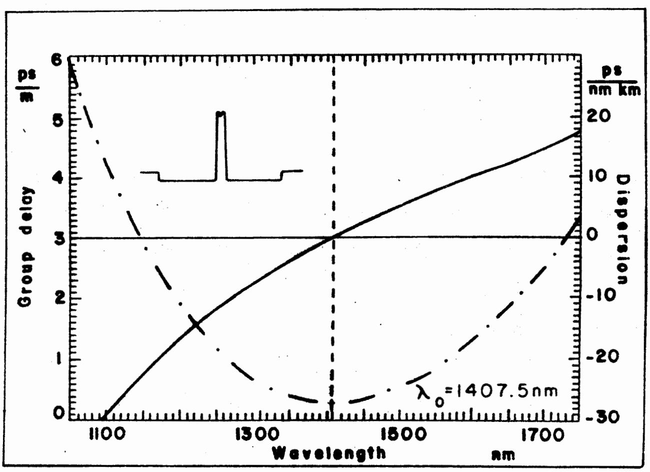

Fig.6 - Group delay and chromatic dispersion of a small core, high step index single mode fibre, showing the effect of waveguide dispersion.

as the triangular profile of fig.7 are required for best performance at 1.55 µm. Dispersion flattened fibers require still more elaborated profiles with different cladding regions as the fibre of fig. 8. The main goal of the fibre designer is to obtain the correct dispersion curve still maintaining at reasonable values other parameters such as spot size, sensibility to bending or microbending,... etc.

Furthermore, these special profiles should be chosen to give the smallest dependence on the radial dimensions, so that the fibre performance remains stable against variations on the pulling conditions.

4. MEASUREMENT METHODS

Most of the measurement methods are based on the direct measurement of the group delay spectrum, which is then smoothed by a least squares fitting equation. Chromatic dispersion is then obtained by simple differentiation of the fitting equation, following eq.(1). Different types of equations are currently used for this least squares fit, depending on the number of the experimental points, the spectral range covered by the measuring equipment and the type of fibre which is being measured. The simplest equation is the three terms Sellmeyer expression

$$\tau(\lambda) = c_1 \lambda^{-2} + c_2 + c_3 \lambda^2 \qquad (6)$$

which describes material dispersion and gives reasonable fits for a small number of delay measurements around the minimum of the delay spectrum. When the spectral range of the measuring equipment is large, covering both the 1.3µm and 1.55µm range, a better fit is obtained with the five terms Sellmeyer expression

$$\tau(\lambda) = c_1 \lambda^{-4} + c_2 \lambda^{-2} + c_3 + c_4 \lambda^2 + c_5 \lambda^4 \qquad (7)$$

which can describe both normal and dispersion shifted fibres over the 1.1µm to 1.7µm spectral range. Dispersion flattened or more complicated fibres can either be described by the five terms Sellmeyer's expression or by a polynomial expression

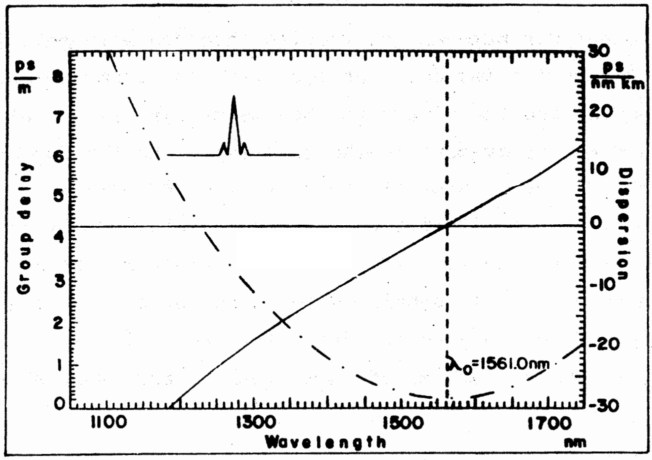

Fig.7 - Group delay and chromatic dispersion of a dispersion shifted single mode fibre.

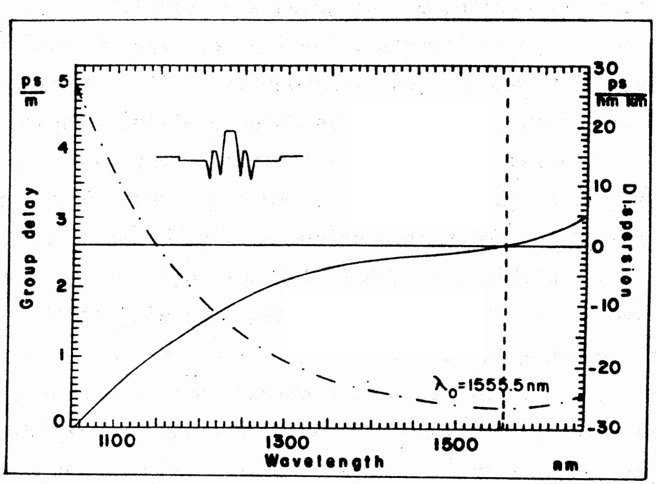

Fig.8 - Group delay and chromatic dispersion of a dispersion flattened single mode fibre.

$$\tau(\lambda) = c_0 + c_1\lambda + c_2\lambda^2 + \ldots + c_N\lambda^N \qquad (8)$$

A comparison between the results obtained with eq.(7) and (8) showed that for most cases covering the 1.1µm to 1.7µm region, the fourth degree polynomial and the five terms Sellmeier expression give equivalent fits and no improvement in the quality of the fit was obtained by increasing the degree of the polynomial fit. Nevertheless, for some special fibres, a small improvement was indeed obtained by increasing the degree of the polynomial fit up to the sixth power of λ.

The experimental techniques for group delay measurements can use time domain, frequency domain and interferometric methods. We will now describe the main features of these methods and make a comparison between their results.

4.1 - Time domain measurements

Time-of-flight measurement corresponds to the direct measurement of the group delay as a function of the wavelength over the 1.1µm to 1.7µm range. Mode locked and *Q*-switched fibre Raman laser[4] is the most common laser of current use as tubable pulsed light source covering the spectral range of interest. The typical experimental arrangement for this kind of measurement is shown in fig.9. A monochromator selects the wavelength of laser pulses which are simultaneously injected into the test fibre and a short piece reference fibre and received by a fast InGaAs detector. The time delay between the test and reference pulses is measured on a high resolution sampling oscilloscope.

Although tunable over the full 1.1µm to 1.7µm spectral range, these laser sources present the disadvantage of being costly and difficult to handle. An alternative source is the array of laser diodes driven by 100ps electrical pulses[5]. Accurate temperature control of the LD is required in order to keep constant the emission wavelength. This feature can actually be used to make a slight tuning of each LD over a limited wavelength range[6]. However, the semiconductor laser diode array lacks of flexibility for measuring fibres with arbitrary dispersion spectra.

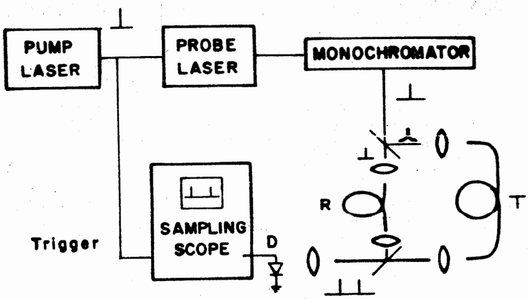

Fig.9 - Experimental set-up for time domain chromatic dispersion measurements.

The time resolution of this method depends on the width of the input light pulses and on the dispersion of the fibre, as seen from eq. (1). The best time resolution is obtained near the wavelength of zero dispersion decreasing by a factor of 2 in the dispersive domain. Typical time resolutions which can be obtained are of the order of 10 - 20 ps/ km although a resolution one order of magnitude better had been reported with the LD array[7].

4.2 - Frequency domain measurements

This technique consists in the measurement of the phase shift of a sinusoidal modulation of the light source as a function of its wavelength. The source can either be a LED or an array of laser diodes. Fig. 10 shows a typical experimental arrangement using a sinusoidally driven LED source and monochromator for wavelength selection. Alternatively, an array of laser diodes such as the one used in pulse delay measurements can also be employed. The phase shift of the modulation signal is directly related to the group delay through the relation $\phi(\lambda) = 2\pi f \tau(\lambda)$.

The time resolution of this method is directly related to the frequency of the modulation signal. The best phase resolution of available vector voltmeters is 0.1°, corresponding to a time resolution of ~$3 \times 10^{-4}\ f^{-1}$ if the optical signal to noise ratio is better than 15 dB. Laser diodes can be modulated at frequencies up to 1 GHz, and the ulti-

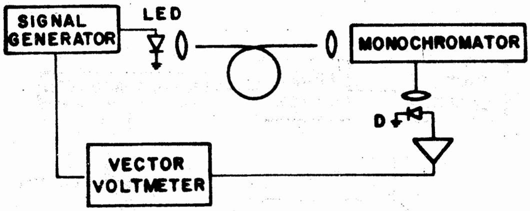

Fig.10 - Experimental set-up for frequency domain chromatic dispersion measurements.

mate resolution which can be attained with LD phase shift techniques is actually limited by the band-width of the detecting system. Using 500 MHz modulation frequency, a time resolution of 0.6 ps can be attained still keeping the dynamic range better then 15 dB.

Laser diode are high power and large bandwith devices, but have the disadvantage of allowing measurements only in discrete wavelength over the spectral range of interest. Nevertheless, the technique provides very accurate delay measurements over several tens of kilometers, allowing the control of long lengths of fibres links.

The use of modulated edge emitting LED continuously covering the full 1.2µm to 1.6µm spectral range partially overcomes the problem of discreteness which arise from LD systems, but the modulation frequency (and hence the time resolution) must be reduced by about one order of magnitude due to the lower bandwidth of the LED. Resolution of ~10ps had been achieved using two 30 MHz modulated LED's to cover the spectral range of interest[8], so that time resolution on group delay measurements of the order of 1ps/km or better can be obtained with ~10 km samples.

A new double modulation technique was recently developed employing a sinusoidally modulated LED source and a second modulation by means of an electro-optic device[9]. The phase signal is then detected on the low frequency beat signal created by the double modulation. This arrangement allows a considerable improvement on the dynamic range of the measurement, due to the greater sensitivity of the low frequency detection. A time resolution of 5.6ps/km was reported over the 1.2µm to 1.6µm spectral range with two LED sources. This corresponds to a considerable improvement over the previous phase shift techniques.

4.3 - Interferometric method

Optical interferometers are systems in which the light signal is splitted in two optical paths and recombined again before being detected. Fig. 11 shows the two configurations of current use in fiber optic interferometry, the Mach-Zender and the Michelson interferometers. In the Mach-Zender the light is splitted at B_1 and recombined at a second beamsplitter B_2 whereas in the Michelson configuration the light is splitted at B, reflected back at the end of the two legs and recombined again at B. Therefore the optical path in the Michelson configuration is twice the physical length of the interferometer's arm. In fibre optic interferometers, the beamsplitters can be replaced by fibre optic single mode 3 dB couplers, rendering the optical connections more reliable and vibration free[10].

When monochromatic light is launched in the interferometer the intensity at the detector is a sinusoidally varying function of the phase difference between the two splitted optical paths

$$I = I_1 + I_2 + 2\sqrt{I.I_2}\cos\phi \tag{9}$$

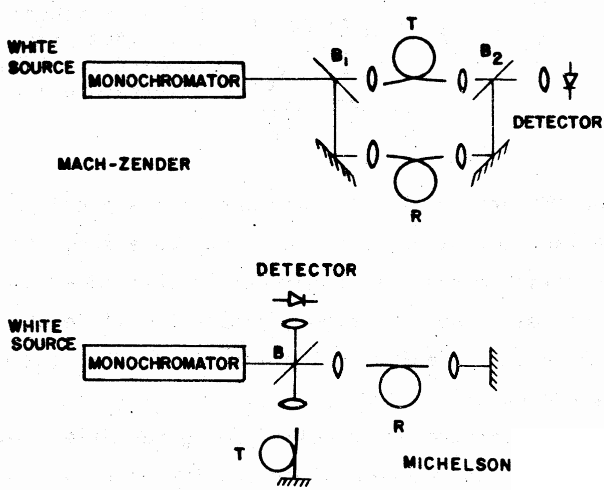

Fig.11 - Mach-Zender and Michelson interferometers for chromatic dispersion measurements. T and R are the test and reference arms of the interferometers.

where I_1 and I_2 are the intensities in each of the interferometer's arms. Phase shifting can be obtained by variation of the optical path in the reference arm either by displacing a mirror or roof top prism in an air path[3,11] or by elastically varying the lenght of the single mode fibre in the reference arm[10].

We now look at what happens when polychromatic light is shined in the interferometer. Incoherent light may be considered as a random superposition of coherent light pulses whose duration, also called coherence time, is given by the spectral width of the light source: $\Delta T \sim \lambda^2/c\Delta\lambda$. Each of these pulses is splitted into two pulses P_1 and P_2 at t=0, as shown in fig. 12, which reach the recombination point at different times τ_1 and τ_2, which are the group delays in each of the interferometer's arms.

If the difference $\tau_2 - \tau_1$ is greater than the coherence time ΔT, there will be no overlap between the pulses P_1 and P_2 and the recombination will occur between pulses with random phase differences. In this case, the cos ϕ term in eq. (9) will average to zero, and no interference will be observed: the interferometer will be in the incoherent regime.

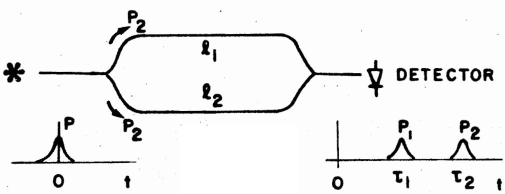

Fig.12 - Schematic of incoherent light propagation and recombination in a Mach - Zender interferometer.

When the arms of the interferometer are tuned pulses P_1 and P_2, will now overlap each other, and since they come from the same imput pulse, their relative phase is coherent. In this case, interference fringes can be seen, and the fringes contrast will depend on the overlap between P_1 and P_2. Maximum fringes contrast will occur when the group delays are exactly tuned $\tau_2 = \tau_1$.

In the interferometric method for group delay measurement the test fibre is inserted in one arm whereas the other arm contains either an accurately known reference fibre or a (non dispersive) air path. The group delay, e.g. the length of the air path, of the reference arm is swept and the system searchs for the maximum fringes contrast. As the wavelength of the light source is changed, the tuning of the interferometer changes according to the variation of the group delay of the test fibre, as shown in fig. 13.

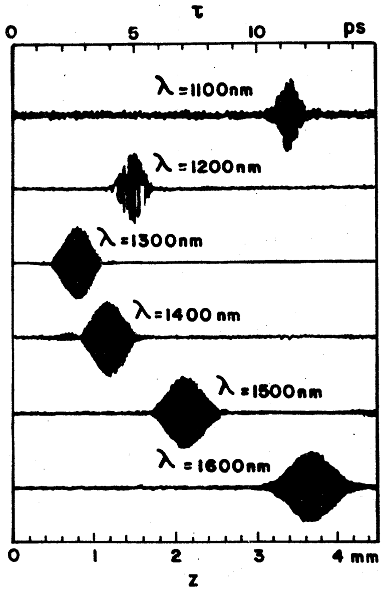

Fig.13 - Interference fringes of different wavelengths in a Michelson interferometer. The Z coordinate is the position of the reflecting mirror at the reference leg.

The direct detection of the interference fringes requires very stable and vibration free interferometers, which may be an inconvenient feature for routine measurements. Several methods have been used for overcoming this problem. The direct detection of noise amplitude in the optical signal had been successfully used as a mesure of fringes contrast, with a reported group delay resolution of 0,1ps [12]. Convolution of the detector output with an ideal interference pattern was also used as a mathematical method for the determination of the position of the fringes patter, the corresponding resolution of 10 fs [13] is one order of magnitude better than the previous methods. The best time resolution reported thus far was obtained by the tuned detection of the interference fringes and Fourier transform techniques for locating the position of the interference pattern [11]. Fig. 14 shows the direct detection of fringes contrast at $\lambda = 1.3\mu m$. Group delay measurements were repeated at the same

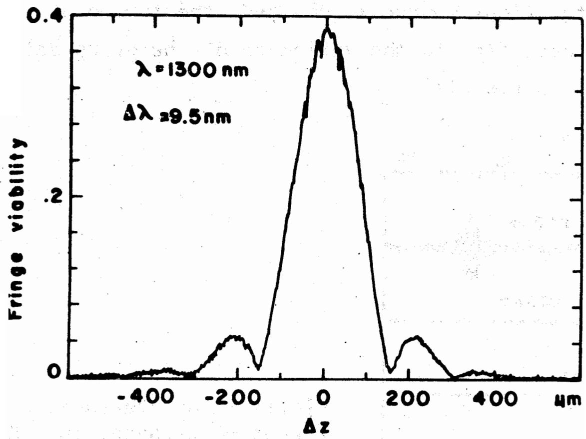

Fig.14 - Direct detection of the Fringes contrast in a Michelson interferometer.

wavelenght in order to obtain the statistics of the time resolution. The results for 10^3 measurements are shown in fig.15. The corresponding group delay resolution is 0.5 ps/km, comparable to the best time resolution obtained from phase shift measurements.

The interferometric method is actually a local measurement technique, such as the index profile, the geometry and the spot size. One could argue whether the results of a local measurement agree with the performance of a long fibre, which corresponds to the average dispersion of all fibre segments. Table 1 shows the comparison between our interferometric measurements and the results obtained with the Raman Laser technique[14] and the five LD phase shift technique[15] over 1.1 km of single mode fibre. The agreement of the three techniques is excellent, even at λ = 1.55μm where the phase shift technique lacks in accuracy due to the small number of measuring points.

The results of the systematic comparison between our interferometric measurements and the phase shift measurement technique[16] for 35 standard fibre samples are shown in figs. 16 and 17. The small systematic deviation in wavelength and dispersion can be explained by the fact that the interferometric measurements were done each 10nm so that the ensemble of experimental delay data used for the theoretical fit is much

Table 1 - Dispersion characteristics of a single mode fibre measured by the phase shift (ϕ), time of fligth (T) and interferometric (I) methods.

	λ (nm)	$D_{1.30}$(ps/nm/km)	$D_{1.55}$(ps/nm/km)
ϕ	1320.6	-1.86	16.19
T	1322	-2.02	15.44
I	1321	-1.83	15.64

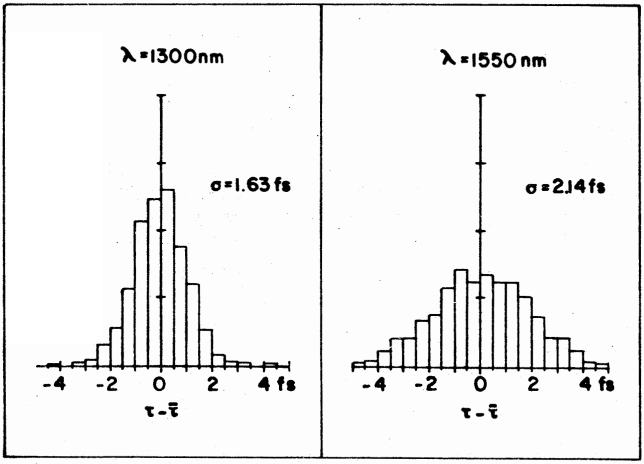

Fig.15 - Accuracy of group delay measurements in an ensemble of 10^3 measurements at 1300 nm and 1550 nm.

richer than the available delay data from the phase shift measurement. Nevertheless, the excellent agreement between the two methods confirms previous studies which indicate that local and long length measurements are in good agreement either in standard or dispersion shifted samples[13,17].

It is clear that when the local parameters such as index profile and core radius are varying along the fibre the chromatic dispersion of each small segment of fibre will be different from piece to piece. In this case, the chromatic dispersion of a cut piece may be different from the mean over the whole fibre. Of course, other local fibre parameters will also present the same unstability. This effect is clearly

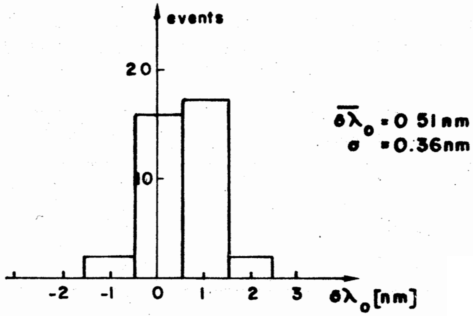

Fig.16 - Comparison between the wavelength of zero dispersion as measured by the phase shift and interferometric techniques.

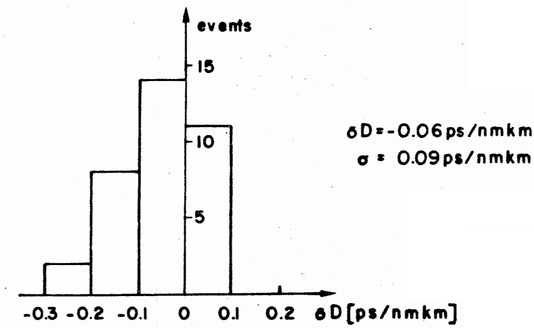

Fig.17 - Comparison between the dispersion value at 1300 nm as measured by the phase shift and interferometric techniques.

present on the results of table 2, where both ends of each fibre sample were measured. The geometry, index profile, cut off wavelength and spot size of the samples were also measured in order to control the origin of the observed difference in chromatic dispersion. It can be clearly seen that geometry variations are responsible for the fluctuation in fibre dispersion, although this effect was partially compensated by an index change from end to end in fibre C.

The main conclusion of this section is that the comparison between the interferometric method and the long fibre methods is reliable provided the fibre parameters are uniform along the fibre. It should be pointed out that for all fibres in which the chromatic dispersion changed significantly from end to end, the geometry and index profile showed variations. In these cases it was the cut off wavelength which showed the most strong variations from end to end, a difference of more than 100nm being easily observed.

Table 2 - Wavelength of zero dispersion of both ends of fibre sample. $\Delta R/R$ is the relative variation of core radius between the internal and external ends.

	A	B	C	D	E	F
λ_0 (external end)	1310	1328	1322	1311	1314	1316
λ_0 (internal end)	1315	1316	1320	1312	1315	1315
$\Delta R/R$ (%)	-3.4	+4.9	+3.6	-	-	-

The interferometric method is very convenient for the development of new fibres such as dispersion flattened fibres. In this case the flexibility in wavelength selection is a fundamental feature for a reliable chromatic dispersion measurement. Furthermore, being a local measurement, the interferometric method may be used to control the stability of the fibre parameters by comparison between samples coming from opposite ends of the fibre.

A final remark can be made concerning the temperature variations during the chromatic dispersion measurements. It is well known that temperature fluctuations induce variations in fibre length and refractive index so that these fluctuations should be avoided during group delay measurements. In an industrial environment, the optical cables are stocked at places whose temperature is in general quite different from that of the characterization laboratory. Therefore when the cable is to be measured it is introduced in the laboratory and a temperature gradient will occur between it and its environment. It is clear that a 1 or 2m fible sample attains thermal equilibrium with the interferometer sample chamber much faster than does a 10 - 20 km cable with is environment. Therefore care must be taken in order to allow temperature stabilization in long length measurement techniques.

5. BIREFRINGENCE EFFECTS

A single spatial mode fibre actually presents two orthogonal polarization modes which are degenerate in a perfect axially symmetric fibre. In a real fibre this degeneracy is lifted either by fibre imperfection such as non-circular core or asymmetric internal stress or by external conditions.Therefore, in real fibres the polarization propagates with different group velocities giving rise to disperson, which is called polarization mode dispersion[18]. A number of different experimental techniques have been used for polarization mode dispersion either in standard single mode fibres or in high birefrigent fibres for coherent transmission or device application.

In standard single mode fibres, polarization dispersion is typically smaller than 0.2 ps/km in long samples. In standard phase shift equipments this dispersion is not observed unless linear polarisers are used at the input and output and the phase is analysed as a function of the injected polarization. However, the time resolution of the method is limited, and results have been reported only for high birefringence fibres[19].

Time domain techniques are also unable to measure this effect in normal fibres, mainly because the duration of the optical pulse is usually limited to ~ 100 ps. Nevertheless, results have also been reported for high birefringent fibres, where the dispersion was greater than the optical pulse widht[20].

Birefringence effects, or polarization mode dispersion, can also be observed with the interferometric technique in high birefringence fibres without the need of linear polarizers. Being actually equivalent to a high resolution time-of-flight measurement, the interference fringes corresponding to the two polarization modes can be directly observed, provided that unpolarised light is used. Fig. 18 shows the two polarization modes of a high birefringence PANDA fibre as measured with the tuned detection of interference fringes. The delay spectron of each polarization mode can be measured as shown in fig. 19 and the polararization mode dispersion will be directly known by the difference between the two delay spectra[21]. The time resolution of the method will depend on the spectral width of the light source. With a 10 nm spectral width, polarization mode dispersion as small as 1 ps/km can be easily measured over the 1.1μm to 1.7μm wavelength range which means a good time resolution for high birefringence fibres. A better time resolution can be obtained by means of a wider spectral width but in this case, the wavelength dependence would be measured with a correspondingly smaller

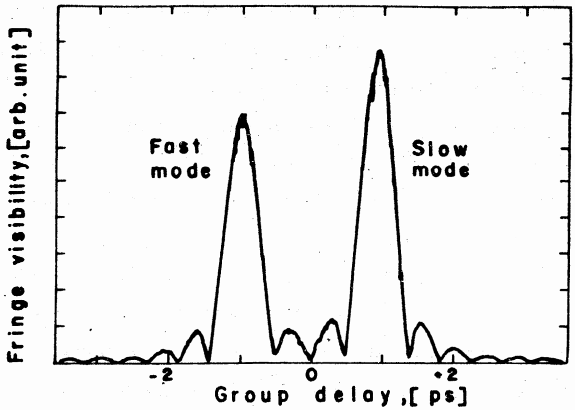

Fig.18 - Interference pattern of a highly birefringent single mode fibre, showing the different delays of each polarization mode.

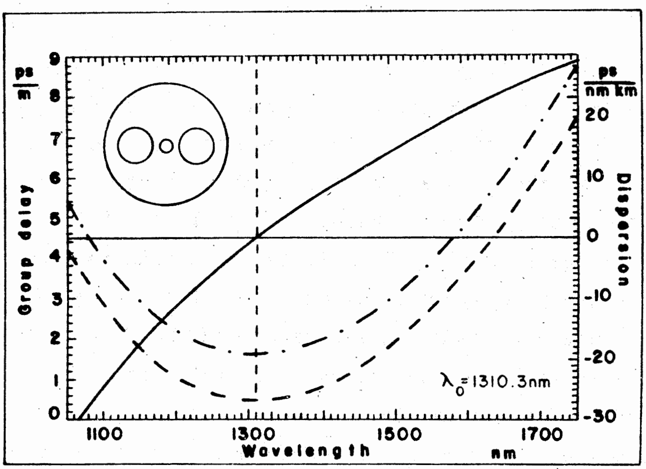

Fig.19 - Group delay, chromatic dispersion and polarization mode dispersion of a highly birefringent single mode PANDA fibre.

spectral resolution.

When measuring standard single mode fibres, birefringence effects are generally too small to affect interferometric group delay measurements. However, fibres with polarization mode dispersion of 0.2 ~ 0.5 ps/km indeed present birefringence effects, which are observed by a strongly wavelength dependend fringes contrast and by an asymmetrical shape of the fringes pattern. Nevertheless, the impact of these birefringence effects are small and actually averaged out by the theoretical fit of the delay data.

It should be pointed out that polarization mode dispersion equally affects phase shift or interferometric measurements. The main difference between the two techniques is that in phase shift measurements the polarization mode dispersion is averaged out in the group delay measurement, whereas in the interferometric technique it appears in the group delay data and is averaged out in the curve fitting for dispersion calculation. Hence, the interferometric method gives an additional information about the fibre which is being measured.

6. CONCLUSION

The three principal techniques for chromatic dispersion measurements in single mode fibres have been compared. The tuned detection of interference fringes and the Fourier transform technique for mathematical location of the fringes envelope brings the time resolution of the interferometric method down to values as small as 1.6 fs in a statistics over 10^3 measurements. This is the best time resolution ever reported in any group delay measurement in single mode fibres. Furthermore, temperature effects which are very critical in group delay measurements can be better controled in a small sample than over several kilometers of fibre sample.

The comparison showed that measurements over long and short samples agree within 0.5 nm for the wavelength of zero dispersion and 0.1 ps/nm km for the dispersion at λ = 1300 nm. This agreement actually corresponds to the reproducibility of any of the three techniques used for fibre characterization.

Global measurements actually correspond to the average value of the local measurements over all sections of the long fibre, so the comparison between interferometric measurements on samples cut from opposit ends of the long fibre allow the control of the stability of the fibre performance along its length. This stability plays an important role if pieces of fibre are to be replaced for maintenance after installation. Furthermore, is should be pointed out that global measurements over ~ 50 km of fibre may be less representative of a cut piece of 2 km than the two-end interferometric control over the cut piece. The best control is indeed the measurement of the chromatic dispersion of each section of installed cable.

Finally the influence of the birefringence on chromatic dispersion measurements was evaluated. The polarization mode dispersion is usually negligible in standard single mode fibres so not affecting either global or local measurements. It was shown that the interferometric technique can be directly used for evaluating the birefringence of high birefringence single mode fibres withoud the need of additional components such as linear polarisers.

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Resumo

São descritas as principais técnicas de medidas de dispersão cromática com ênfase especial nos métodos interferométricos. As técnicas são comparadas com respeito aos seus resultados, vantagens e limitações. Avalia-se as influências de efeitos da birefringência nas medidas de dispersão cromática.