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UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

INTERNATIONAL CENTRE FOR SCIENCE AND HIGH TECHNOLOGY

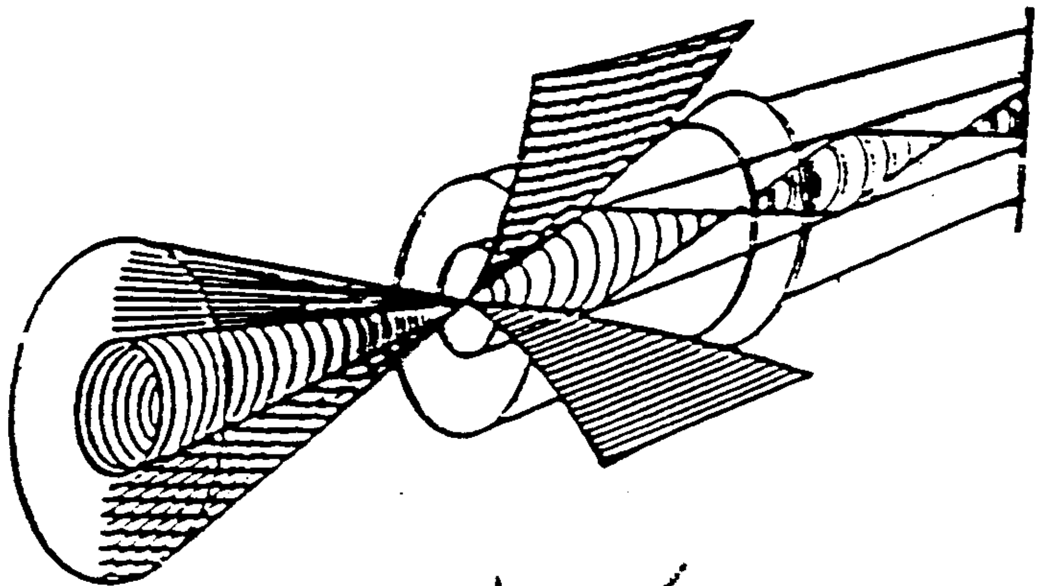
H4.SMR/540-26

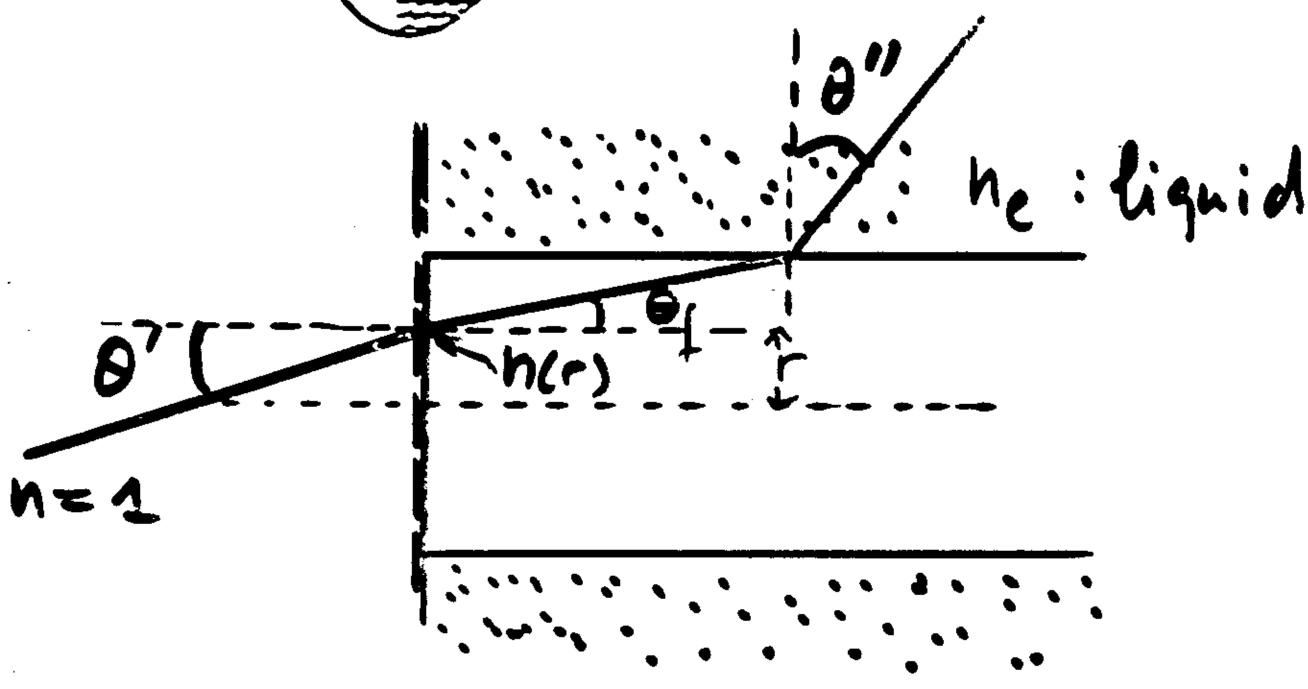
Second Training College on Physics and Technology of Lasers and Optical Fibres

21 January - 15 February 1991

Fibre Theory Fabrication Characterization

J. Pellaux
Universitè de Physique/Dpnc
Geneva
Switzerland

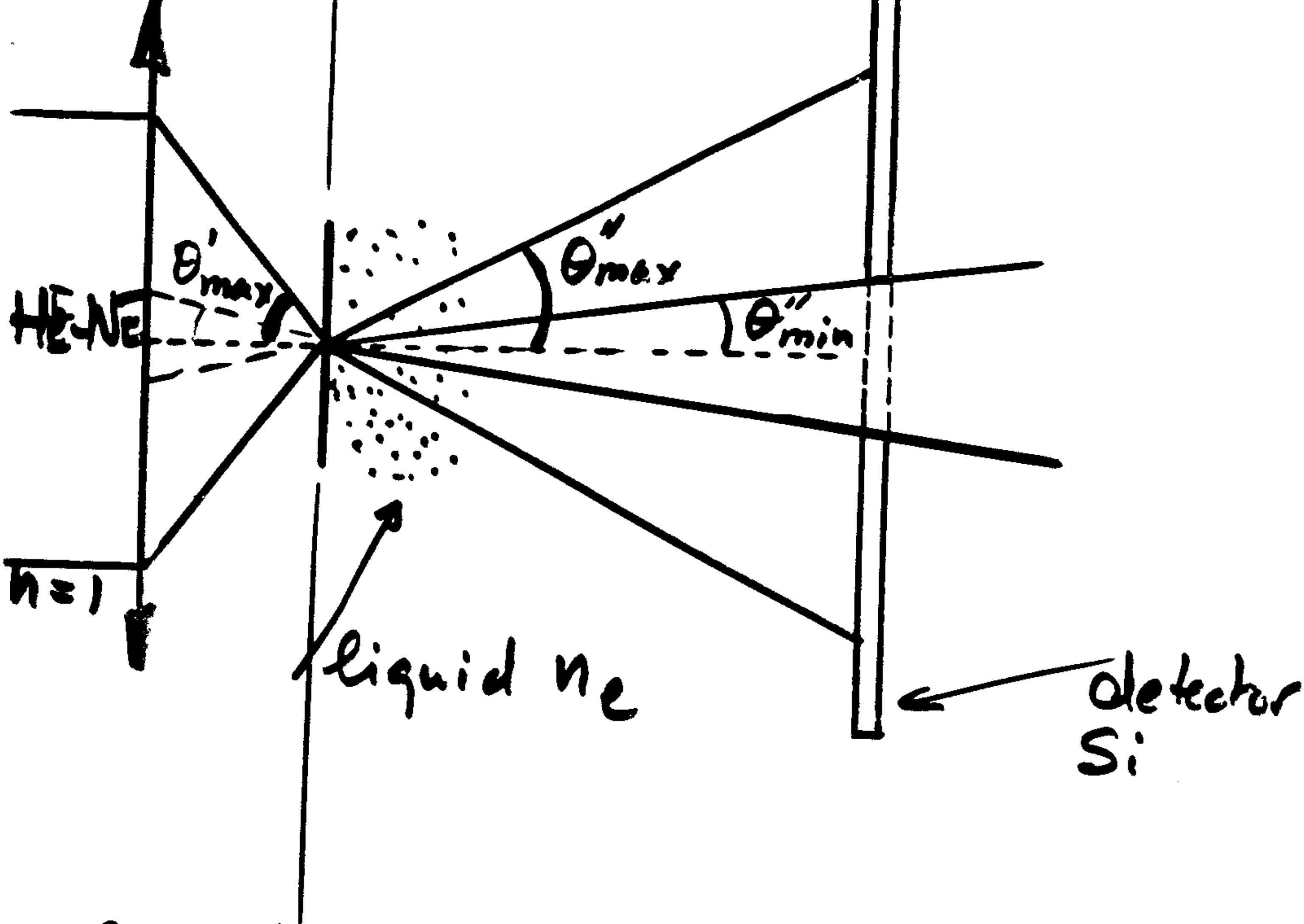




$$\sin\theta' = n(r)\sin\theta_f$$

$$n(r)\cos\theta_f = n_e\cos\theta''$$

$$\underline{\sin^2\theta' = n^2(r) - n_e^2 + n_e^2\sin^2\theta''}$$



Spot lambertian

$$dP = I_0 \cos\theta' \sin\theta' d\theta' d\varphi$$

$$P(r) = \frac{I_0}{2} \int_0^{2\pi} d\varphi \int_{\sin^2\theta'_{min}}^{\sin^2\theta'_{max}} d(\sin^2\theta')$$

$$P(r) = \pi I_0 \left[\sin^2\theta'_{max} - \sin^2\theta'_{min}\right]$$

Light power over the detector

$$P(r) = \pi I_0 \left(\sin^2\theta'_{max} - n_\ell^2 \sin^2\theta''_{min} + n_\ell^2 - n^2(r)\right)$$

Spot in the fiber cladding

$$P_{cl} = \pi I_0 \underbrace{\left(\sin^2\theta'_{max} - n_\ell^2 \sin^2\theta''_{min}\right.}_{P_\ell} \left. + n_\ell^2 - n_{cl}^2\right)$$

P_{cl} : light power in the cladding

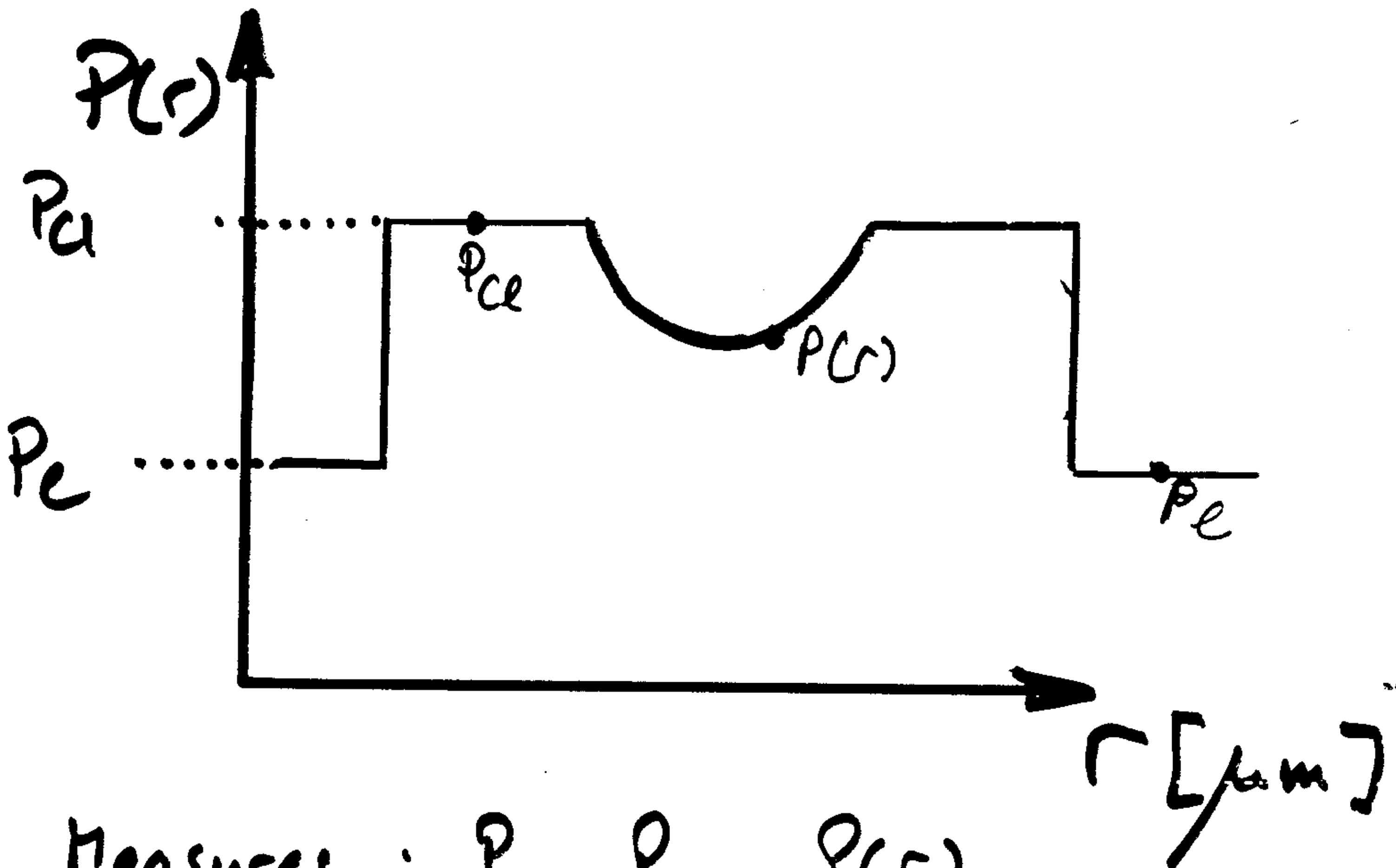
P_ℓ : light power in the liquid

$$P_{cl} = P_\ell + \pi I_0 (n_\ell^2 - n_{cl}^2)$$

$$\Rightarrow \pi I_0 = k = \frac{P_\ell - P_{cl}}{n_{cl}^2 - n_\ell^2}$$

(calibration)

$$n^2(r) = n_l^2 - \frac{P(r) - P_l}{k}$$



Measures : P_l , P_{cl} , $P(r)$

with n_l $\Longrightarrow$ calibration : k

Measure : $P(r)$ $\Longrightarrow$ $n(r)$

NR 8700 opo sa V8.a 16.02.89 - 1 -

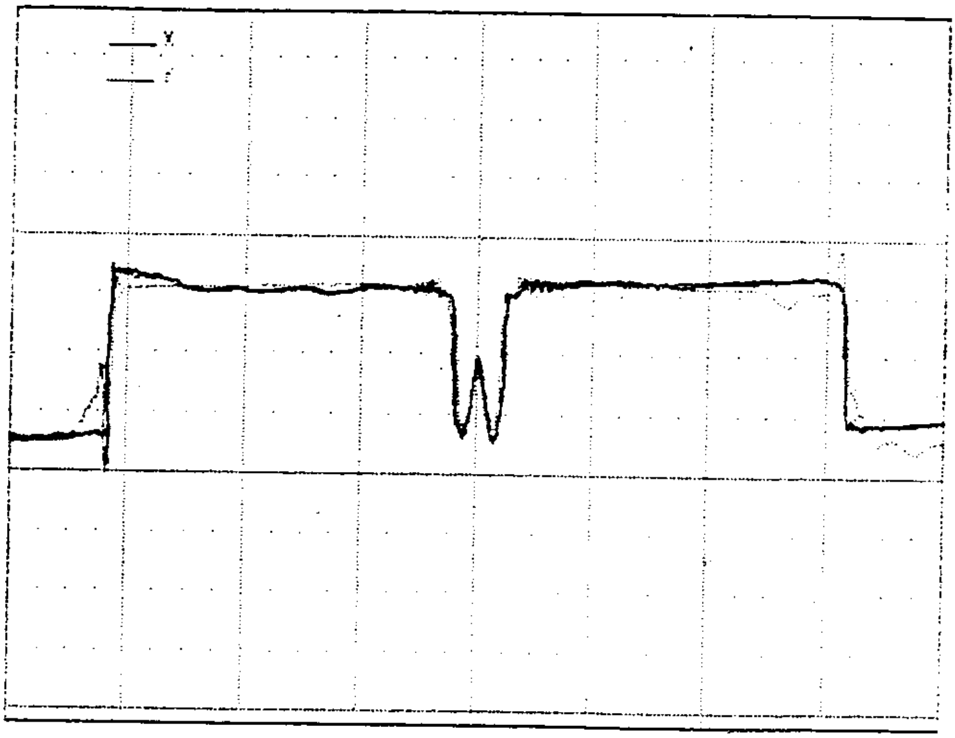
Experiment : TEST SOFTWARE POUR F.O.I

Experiment number: 1

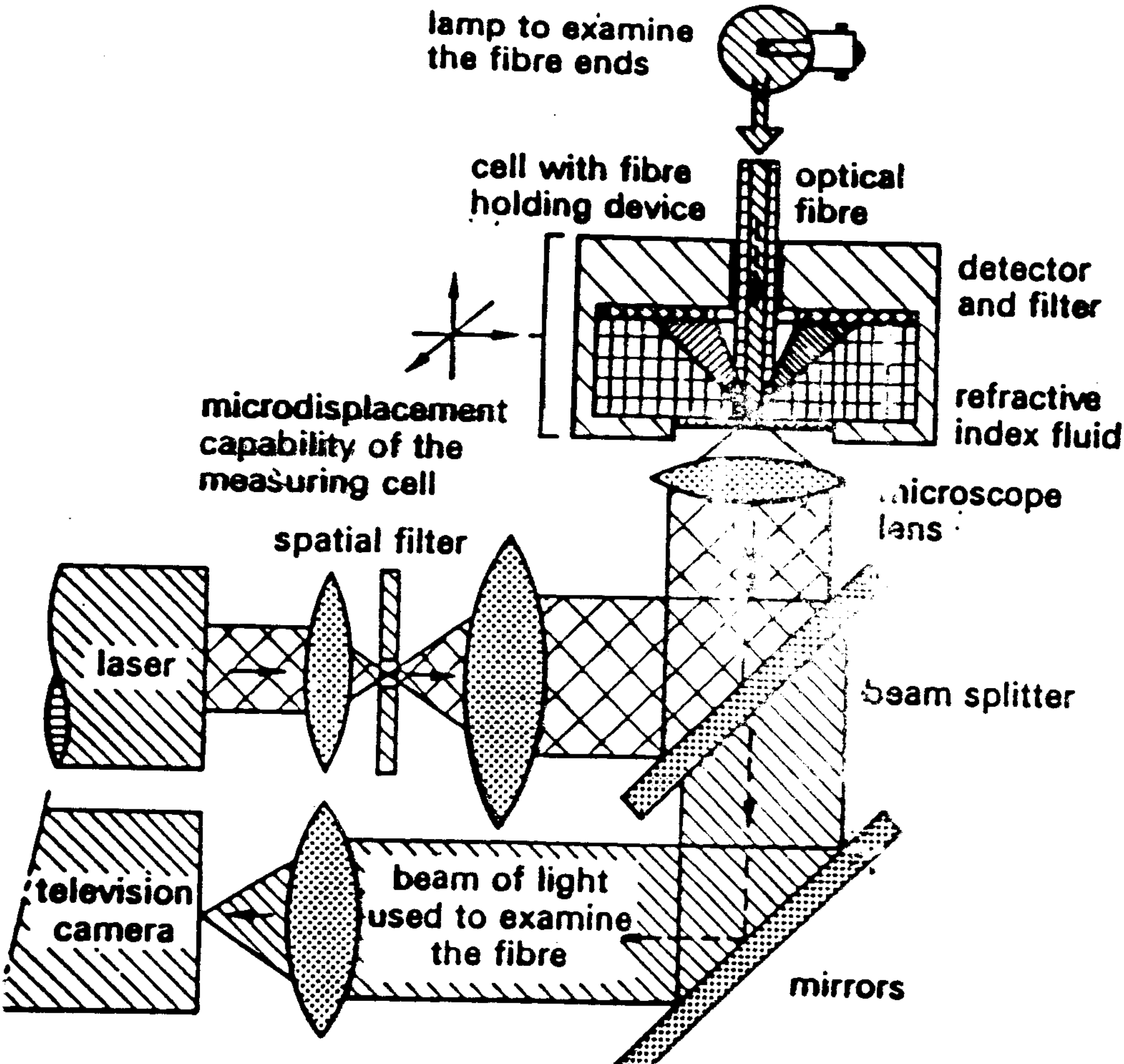
Fibre Name :

Comment : F.O.I CONFLANS STE HONORINE

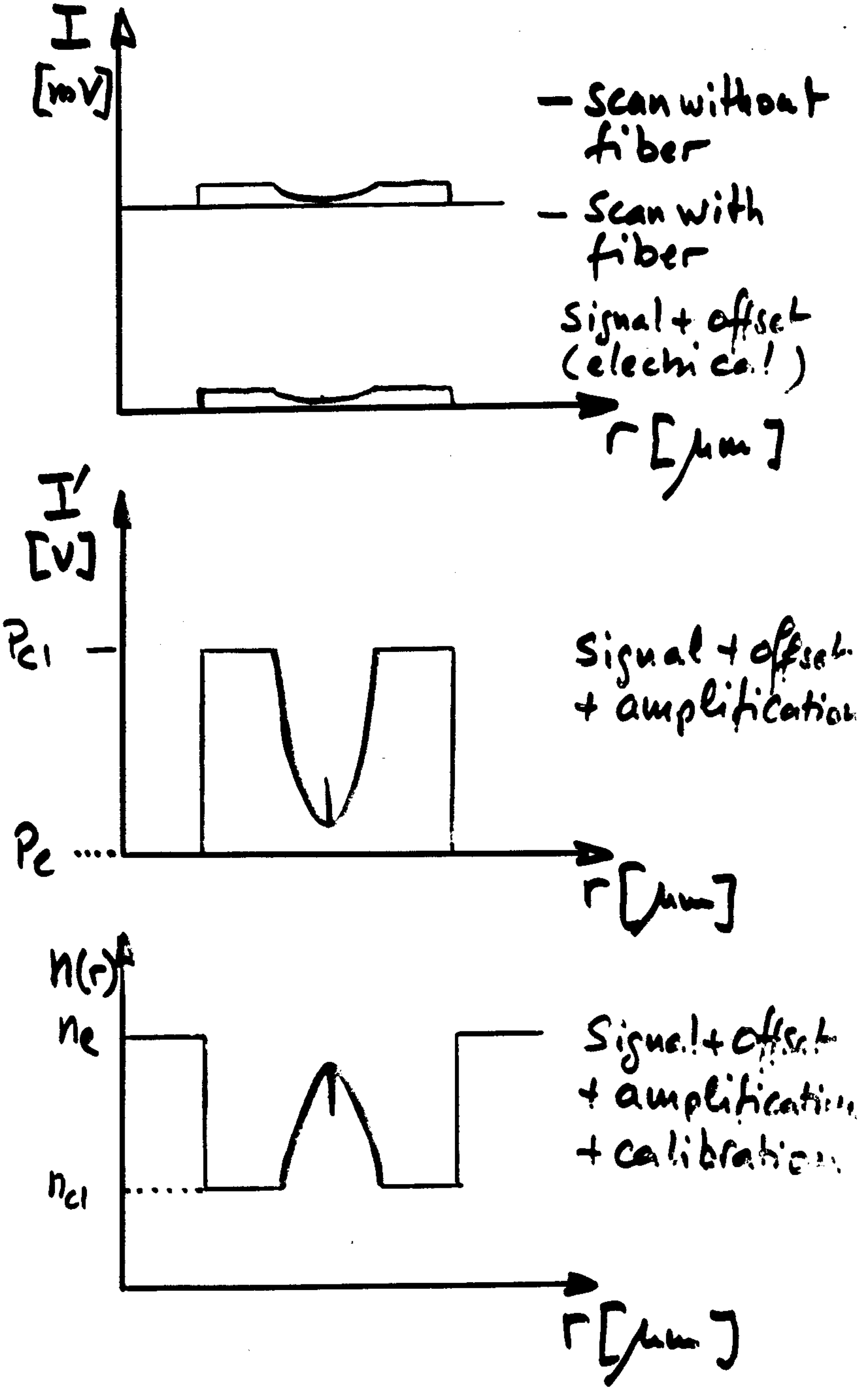
| X Y control |



Measurement done the 16.02.89 by OPS INSTRUMENTS / DC

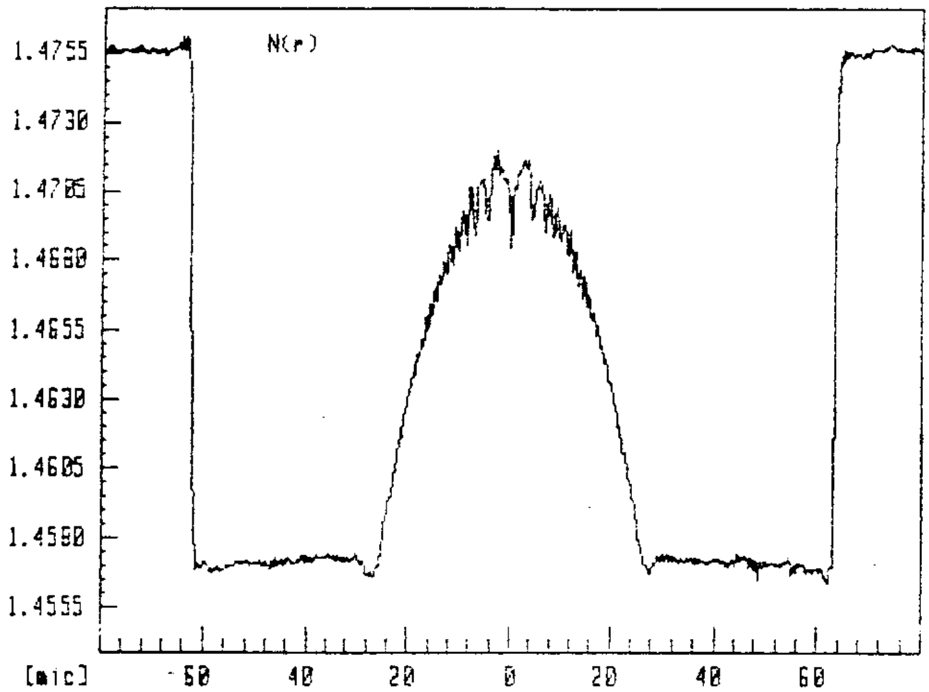


igure 16—Optical device to measure the refractive index

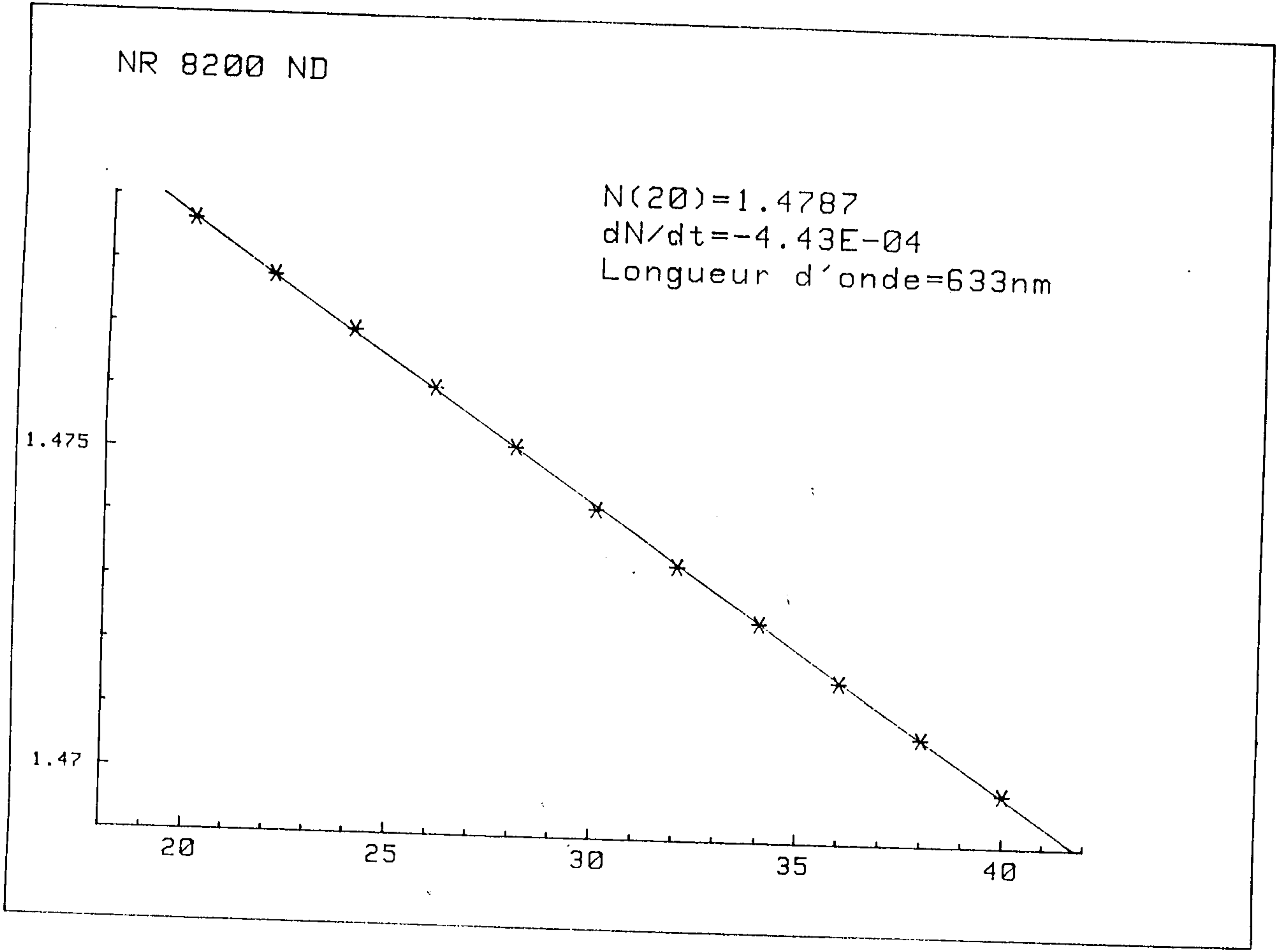

I [mV]
- scan without fiber
- scan with fiber
Signal + offset (electrical)
r [µm]
I' [V]
P_{cl}
P_e
Signal + offset + amplificatio
r [µm]
n(r)
n_e
n_{cl}
Signal + offset + amplificatio + calibratio
r [µm]

Measurement N(r) X Axis

Numerical aperture : 0.21

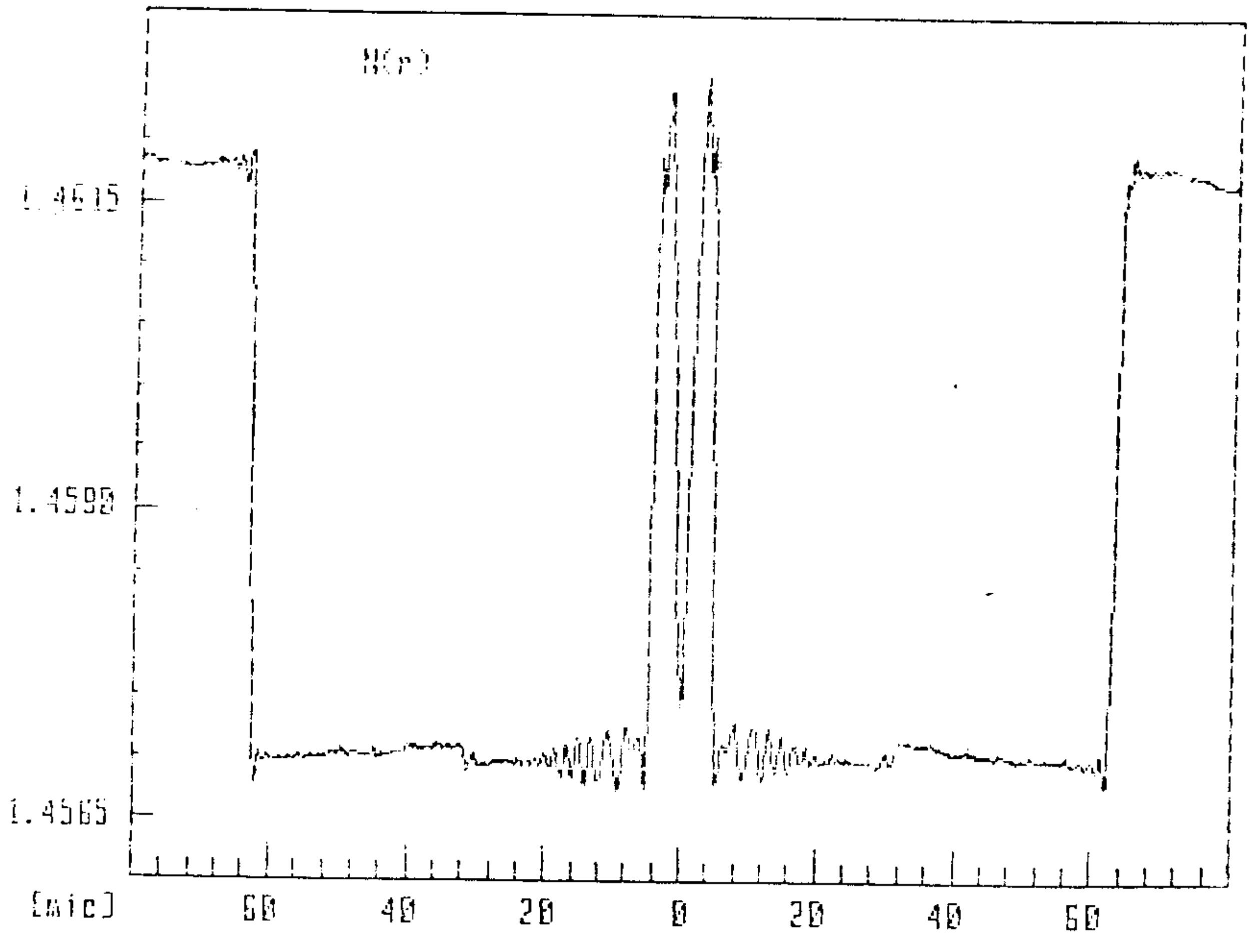


Measurement done the 2-12-1986 by


NR 8200 ND
N(20)=1.4787
dN/dt=-4.43E-04
Longueur d'onde=633nm
1.475
1.47
20
25
30
35
40

Experiment : NR 8200
Fibre Name : Mono-mode
Comment : TRAINING

Measurement N(r) Y Axis



Measurement done the 27/06/86 by AL

... to obtain an error-free calibration.

5.3 Measuring the geometric parameters of an optical fibre

In order to determine the diameters of the core and the cladding, a series of scannings has to be carried out on the same section of the fibre. Figure 28 shows graphically how this measurement is made.

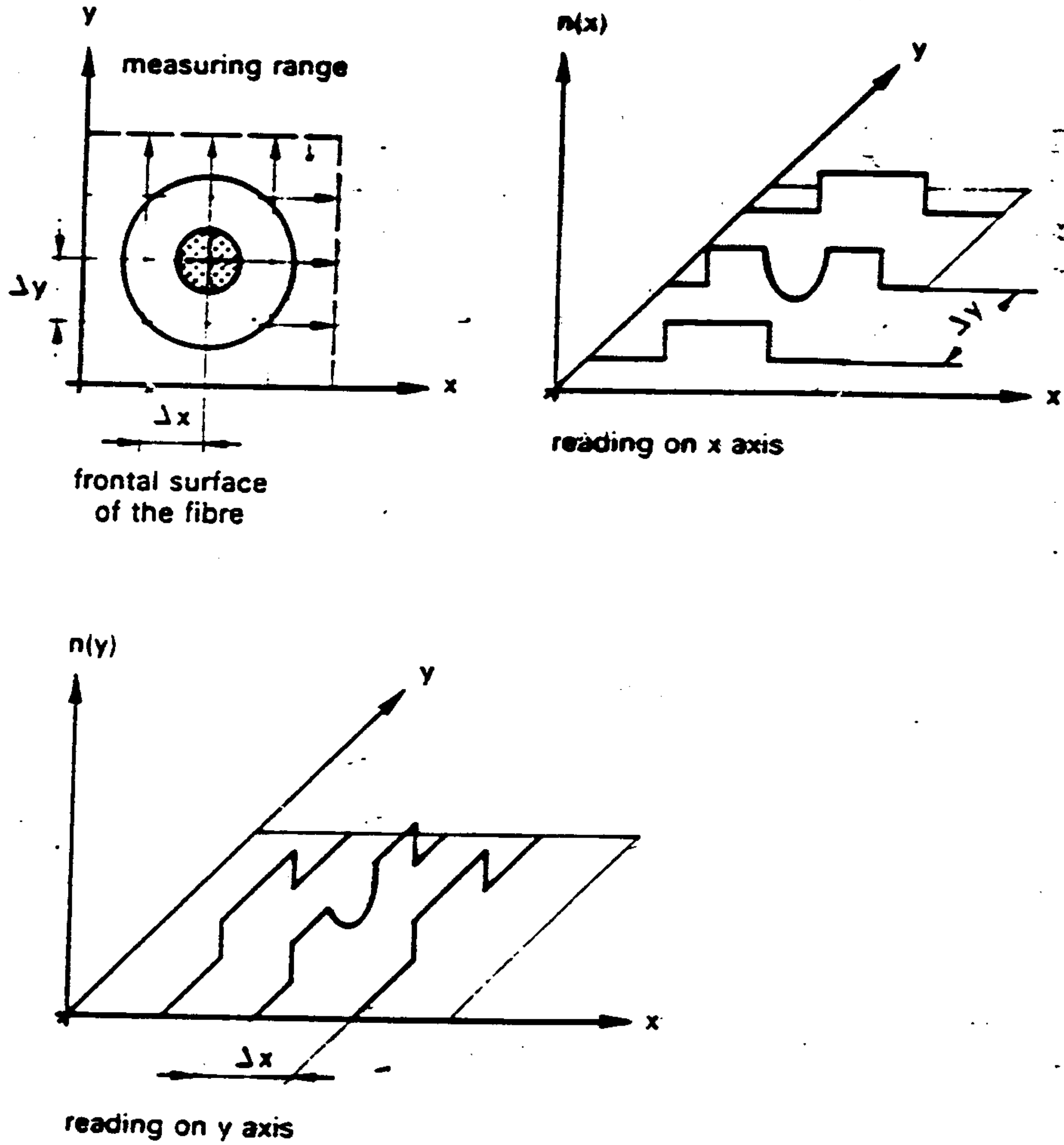


Figure 28—Multiple scannings

5.3.1 Diameter of the cladding

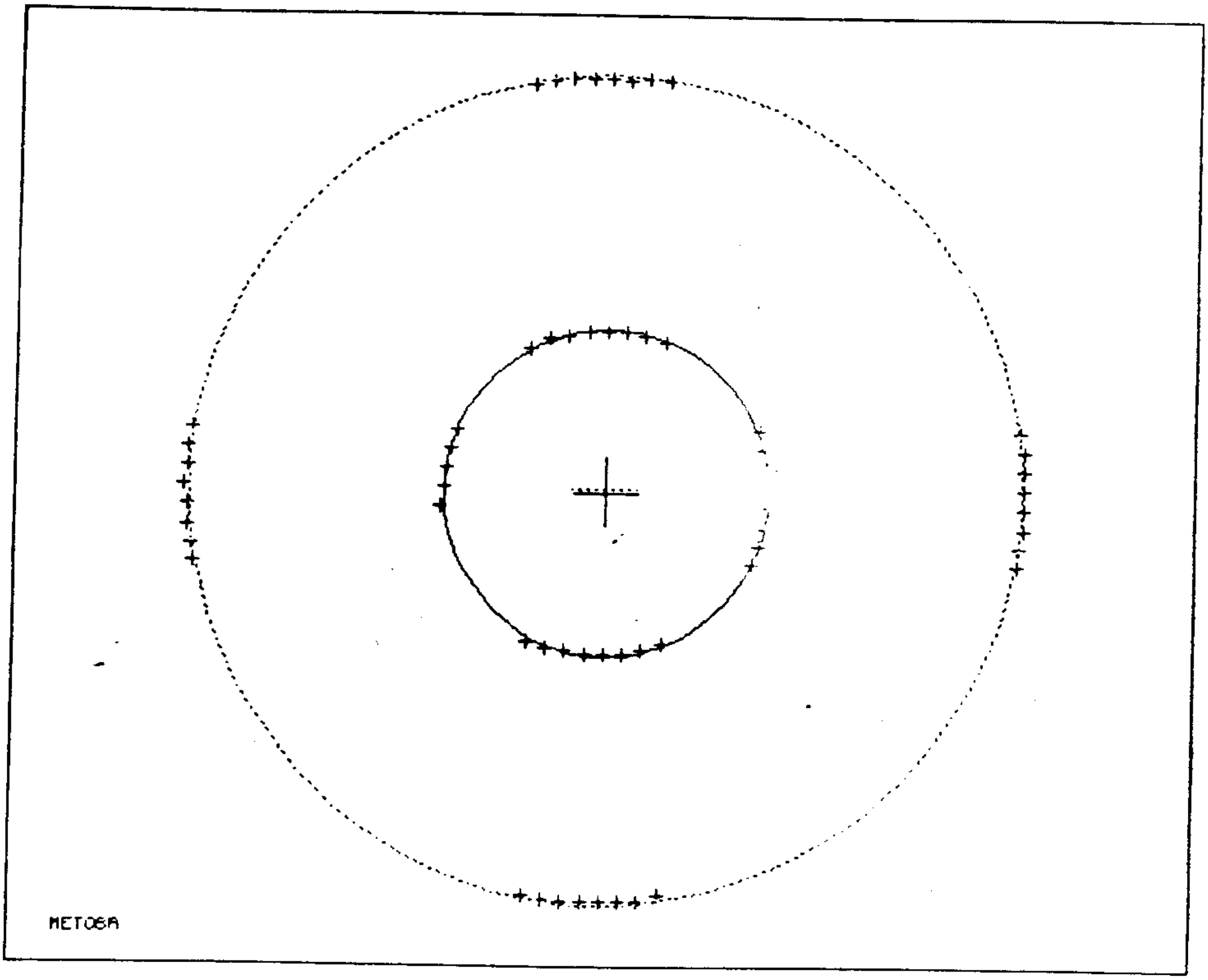
All the points which measure the outside edge of the cladding

GEOMETRIE AUX MOINDRES CARRES

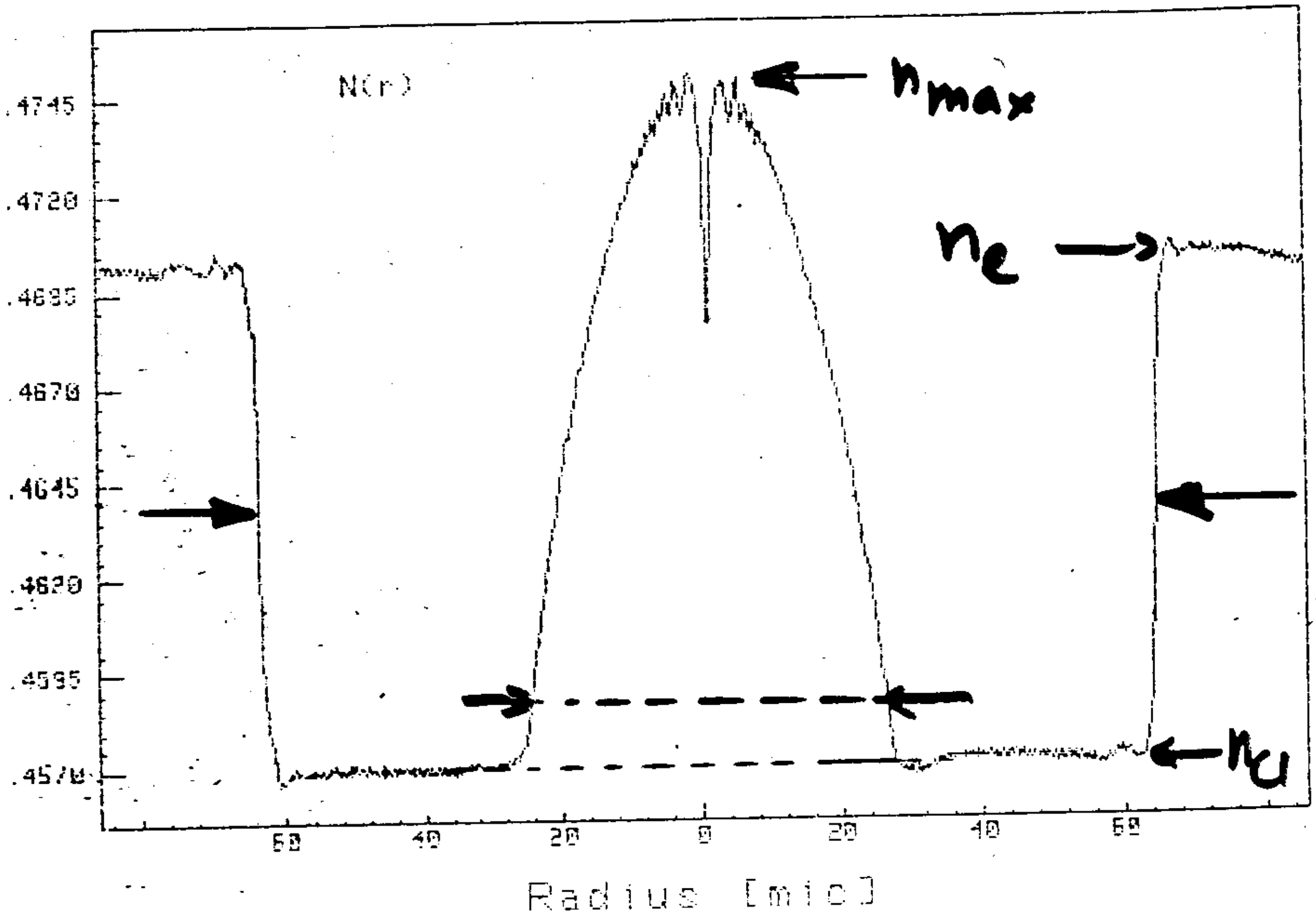
Diametre du coeur : 50.4 , erreur estimee : .29 microns

Diametre de la gaine : 128.5 , erreur estimee : .45 microns

erreur de concentricite coeur/gaine : .0105



MESSUNG N(r) Achse Y



Ø cladding 50% $n_e - n_{cl}$

Ø core 10% $n_{max} - n_{cl}$

Experiment : NR 8200

Fibre Name : Mono-mode

Comment : TRAINING

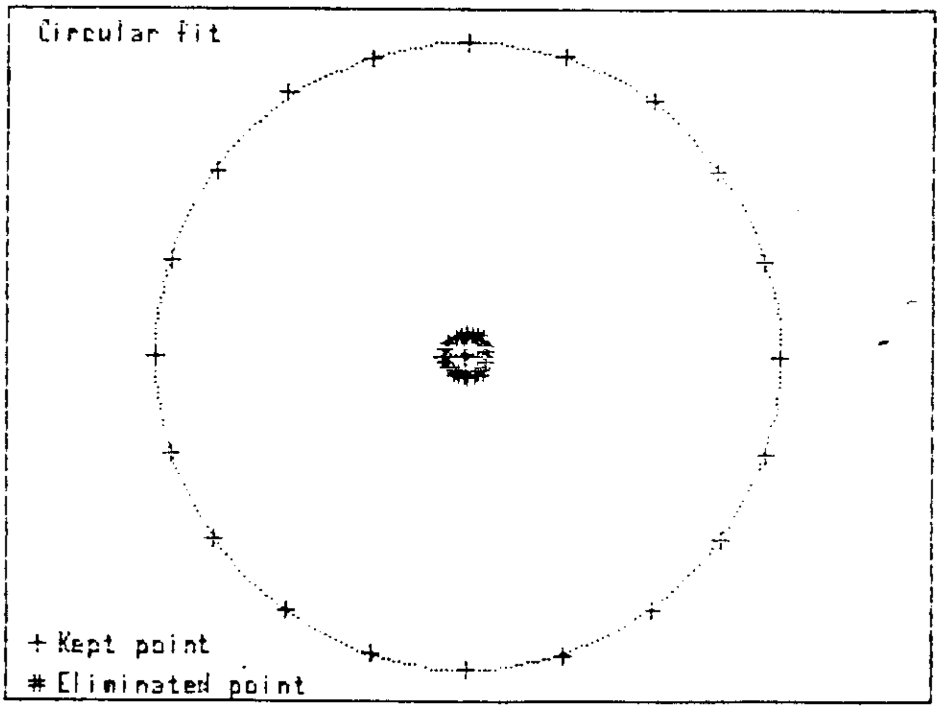
N R 8 2 0 0 Geometry

Circular fit

Unit = micron

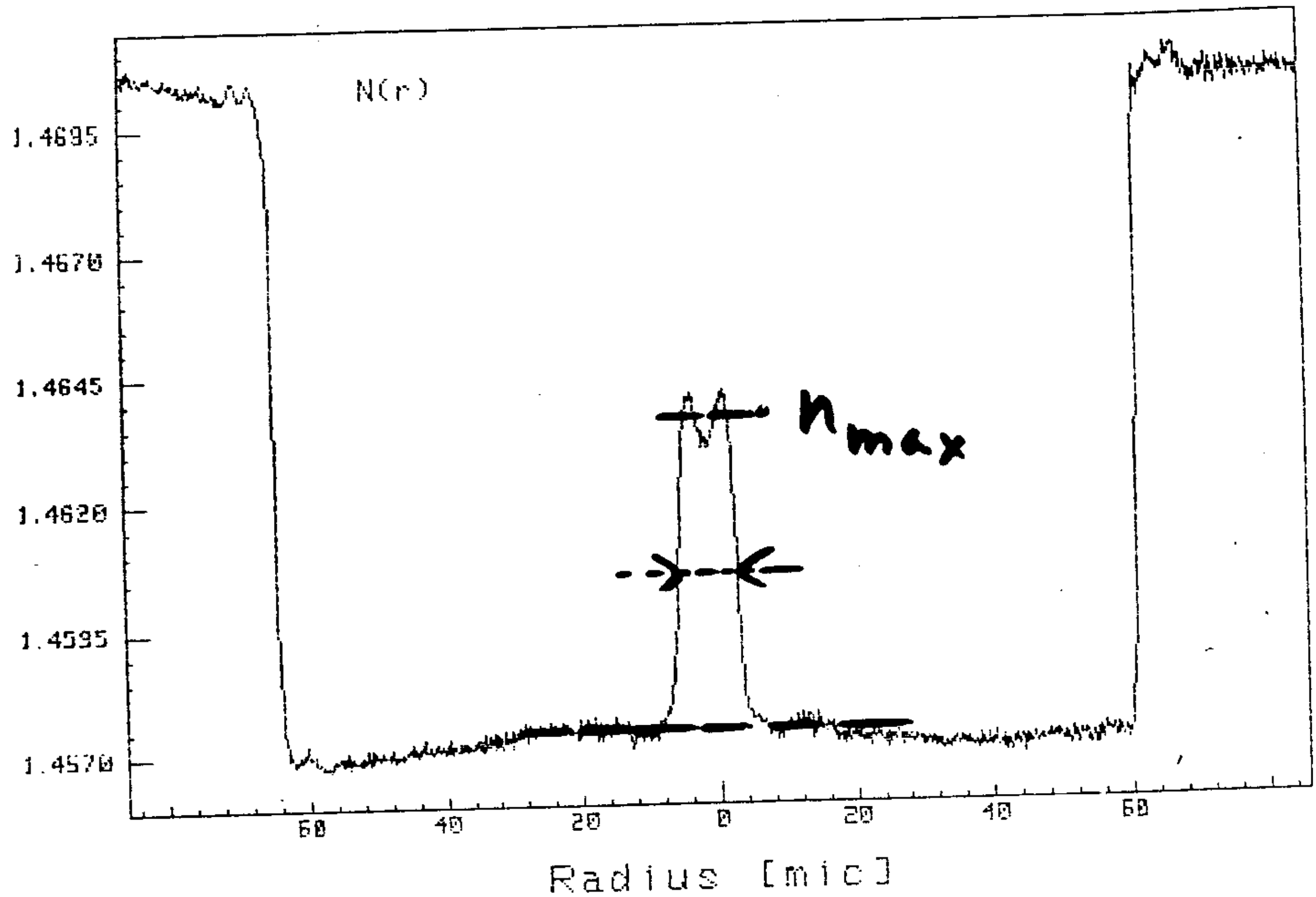
Distance between centers: 0.2

Limit	Kept points	Diameter	St.deviation
Cladd.	20 Points	126.3	0.7
Core	14 Points	8.8	0.1



Measurement done the 27/06/86 by AL

MESSUNG N(r) Achse Y



Ø Cladding 50% $n_e - n_{ce}$

Ø core 50% $n_{max} - n_{ce}$

Geometry by the Refracted Near Field method

Performances

Spatial resolution
given by Ø spot 0.6 – 1 μm

Spatial calibration
given by step motor : 0.1 μm

precision of measure
after statistical computation:
~ 0.3 μm

Refractive index resolution:
$\Delta n \leq 10^{-4}$

Experiment : TEST SOFTWARE POUR F.O.T

Experiment number: 1

Fibre Name :

Comment : F.O.T CONFLANS STE HONORINE

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+--------------------------+
!"3d" drawing:             !
+--------------------------+
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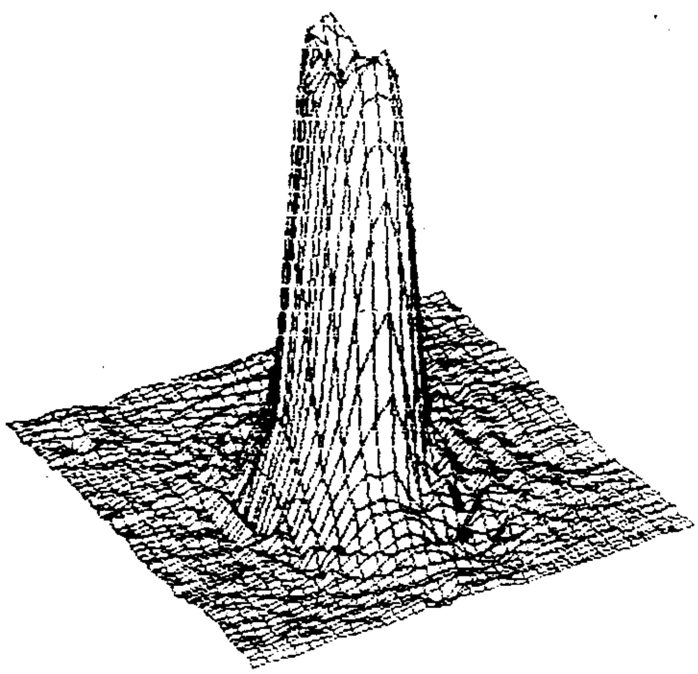


Size in X: 30.0 [mu] Step in X: 0.5 [mu]
Size in Y: 30.0 [mu] Step in Y: 1.0 [mu]

Measurement done the 17.02.89 by OPG INSTRUMENTS / DC

Experiment : TEST SOFTWARE POUR F.O.I

Experiment number: 1

Fibre Name :

Comment : F.O.I CONFLANS STE HONORINE

N R 8 2 0 0 Geometry

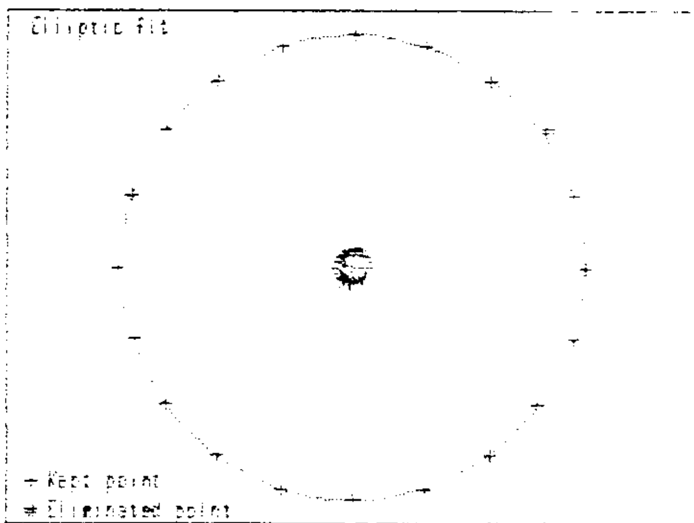
Elliptic fit 50.0 %

Unit = micron

Distance between centers: 0.2

Concentricity error: 2.73 %

Limit	Kept points	Big-axis	Small-axis	Pr.deviation	Non-circularity
Cladd.	19 Points	125.0	125.8	[illegible]	0.29 %
Core	20 Points	9.0	7.8	[illegible]	16.99 %



Measurement done the 16.02.89 by OPG INSTRUMENTS / DC

Experiment : TEST SOFTWARE POUR F.I.I

Experiment number :

Fibre Name :

Comment : F.I.I CONFLANS STE HONORINE

N R 8 Z 0 0 Geometry

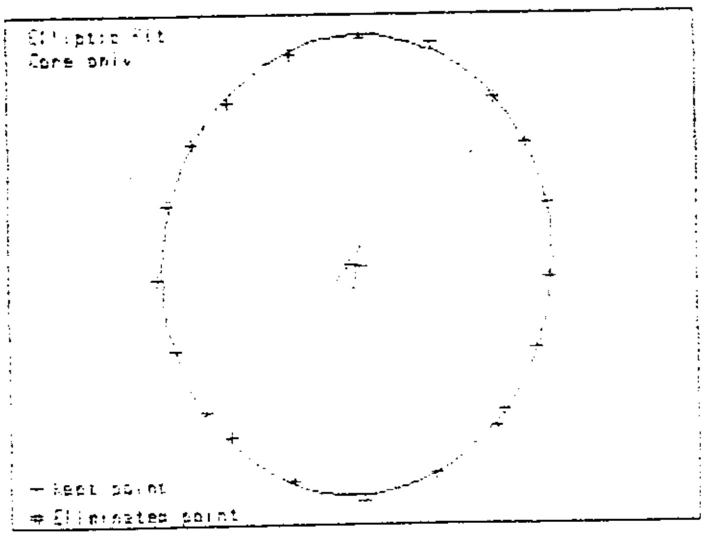
Elliptic fit 50.0 %

Unit = micron

Distance between centers: 0.2

Concentricity error: 2.72 %

Limit	Kept points	Big-axis	Small-axis	St.deviation	Non-circularity
Cladd.	19 Points	125.0	125.5	0.5	0.28 %
Core	20 Points	9.0	7.5	0.1	16.99 %



Measurement done the 16.02.89 by OPG INSTRUMENTS / DC

Experiment : DCI HB

Experiment number: 2

Fibre Name : Coupleur Panda

Comment : Cargille liquide

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|"3d" drawing:              |
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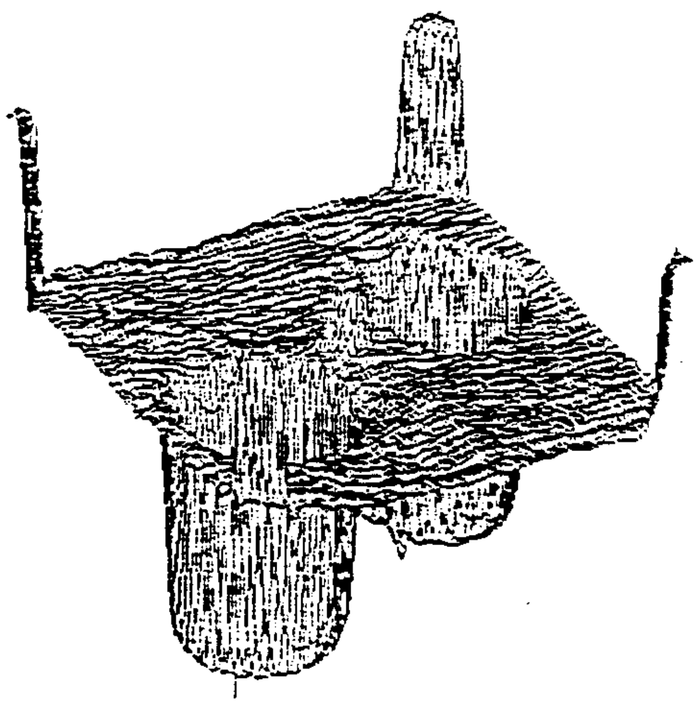


Size in X: 96.0 [mu] Step in X: 1.2 [mu]
Size in Y: 96.0 [mu] Step in Y: 1.2 [mu]

Measurement done the 22.01.89 by GAP University of Geneva, NG

Filing code: CPanda

Figure 7 : Fibre panda du type constituant le coupleur
A, B et C : profil d'indice
D et F : géométrie
G et H : dispersion chromatique.

Experiment : DCI HB

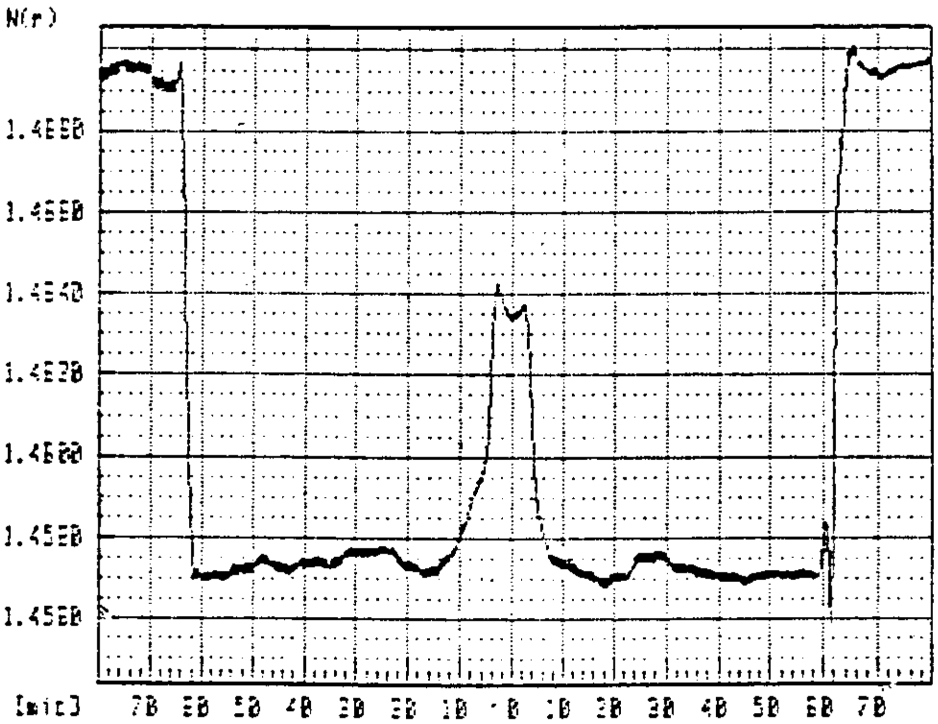
Experiment number: 4

Fibre Name : Coupleur Panda

Comment : Cargille liquide

```
+--------------------------+
| Measurement N(r)  X Axis |
+--------------------------+
```

Delta N: 0.498 %



Measurement done the 22.01.89 by GAP University of Geneva, NG

Filing code: CPanda

fig 7c

Experiment : DCI HB

Experiment number: 5

Fibre Name : Coupleur Panda

Comment : Cargille liquide

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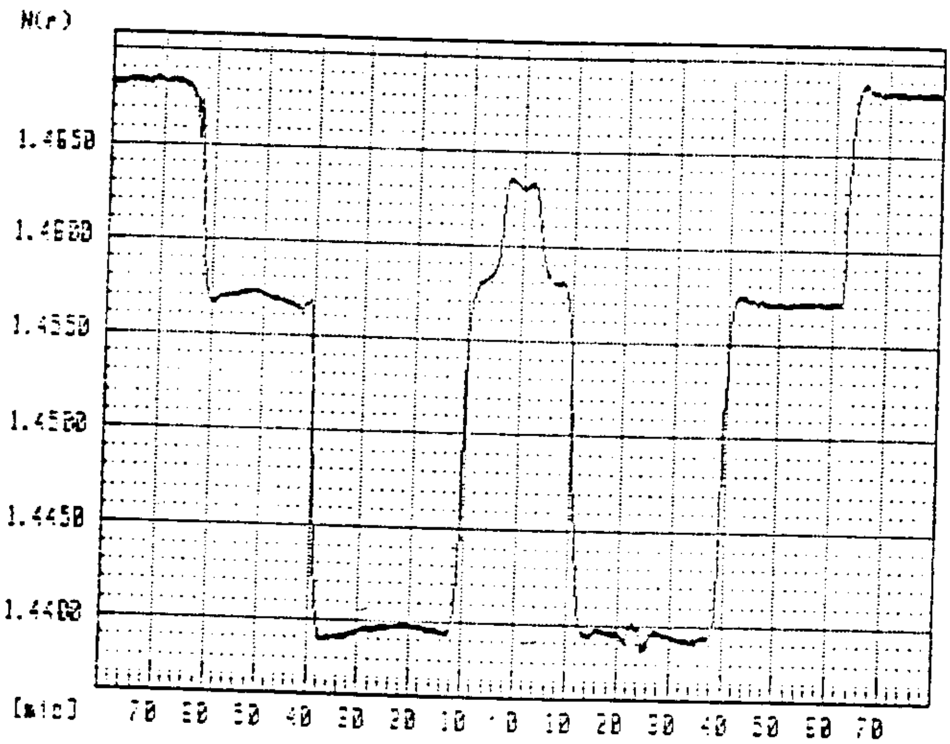
+----------------------------+
¦ Measurement N(r)  Y Axis  ¦
+----------------------------+
```

Delta N: 1.654 %



Measurement done the 22.01.89 by GAP University of Geneva, NG

Filing code: CPanda

fig 7B

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+---------------------------+
|contour lines              |
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```

Experiment : DCI HB

Experiment number: 5

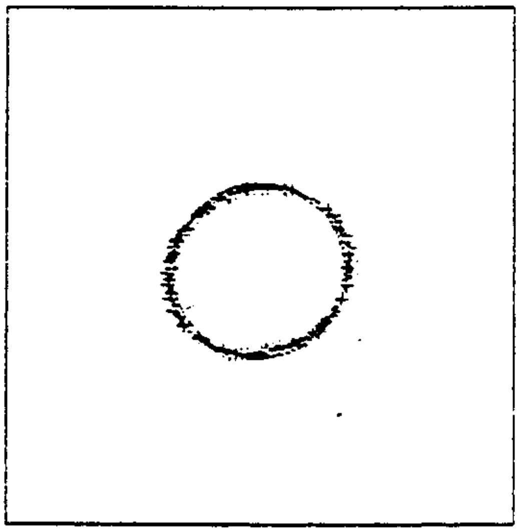
Fibre Name : Coupleur Panda

Comment : Cargille liquide

unit = micron N(R) = 1.46038 % = 50.0

Circular fit: diameter = 8.08
center X = 11.93 Y = 11.81
standard deviation = 0.42

Elliptic fit: large axis = 8.71 small axis = 7.54
non circularity = 14.29 %
center X = 11.93 Y = 11.82
standard deviation = 0.12



Measurement done the 22.01.89 by GAP University of Geneva, NG

fig. 7F

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+---------------------------+
|contour lines              |
+---------------------------+
```

Experiment : DCI HB

Experiment number: 2

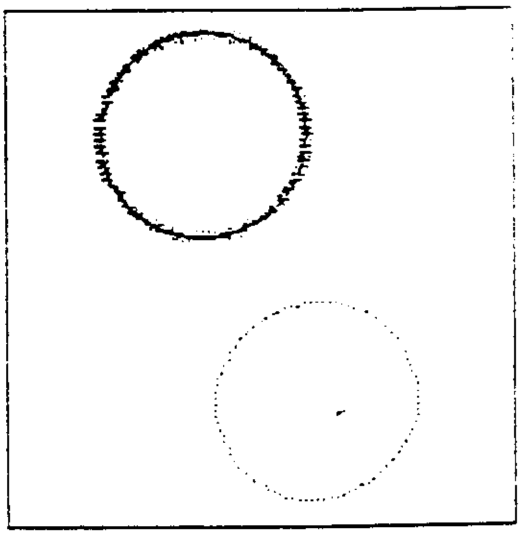
Fibre Name : Coupleur Panda

Comment : Cargille liquide

unit = micron N(R) = 1.45475 % = -50.0

Circular fit: diameter = 38.14
center X = 37.60 Y = 73.03
standard deviation = 0.61

Elliptic fit: large axis = 38.89 small axis = 37.42
non circularity = 4.10 %
center X = 37.60 Y = 73.03
standard deviation = 0.25



Measurement done the 22.01.89 by GAP University of Geneva, NG

fig 7E

ard a Standard ition

itiated, Mode Field Diameter be a Parameter in Turmoil

: and Casey Shaar

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surement
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above its

cutoff wavelength. Mode field diameter is analogous to the core diameter in multimode fibers, except that in singlemode fibers not all the light is carried through the core (Figure 1). Near the cutoff wavelength, a small percentage of light is carried in the cladding. In general, this percentage increases in proportion to the wavelength of the source.

MFD's impact on splice loss and microbend sensitivity is easy to see. If a large difference in mode field diameter exists at the splice point, a high splice loss can be expected. A large MFD will make the task of splicing easier, but it will also make the fiber more susceptible to microbending losses. Knowing these tradeoffs, fiber manufacturers can determine the best nominal value for the MFD. Data from system designers

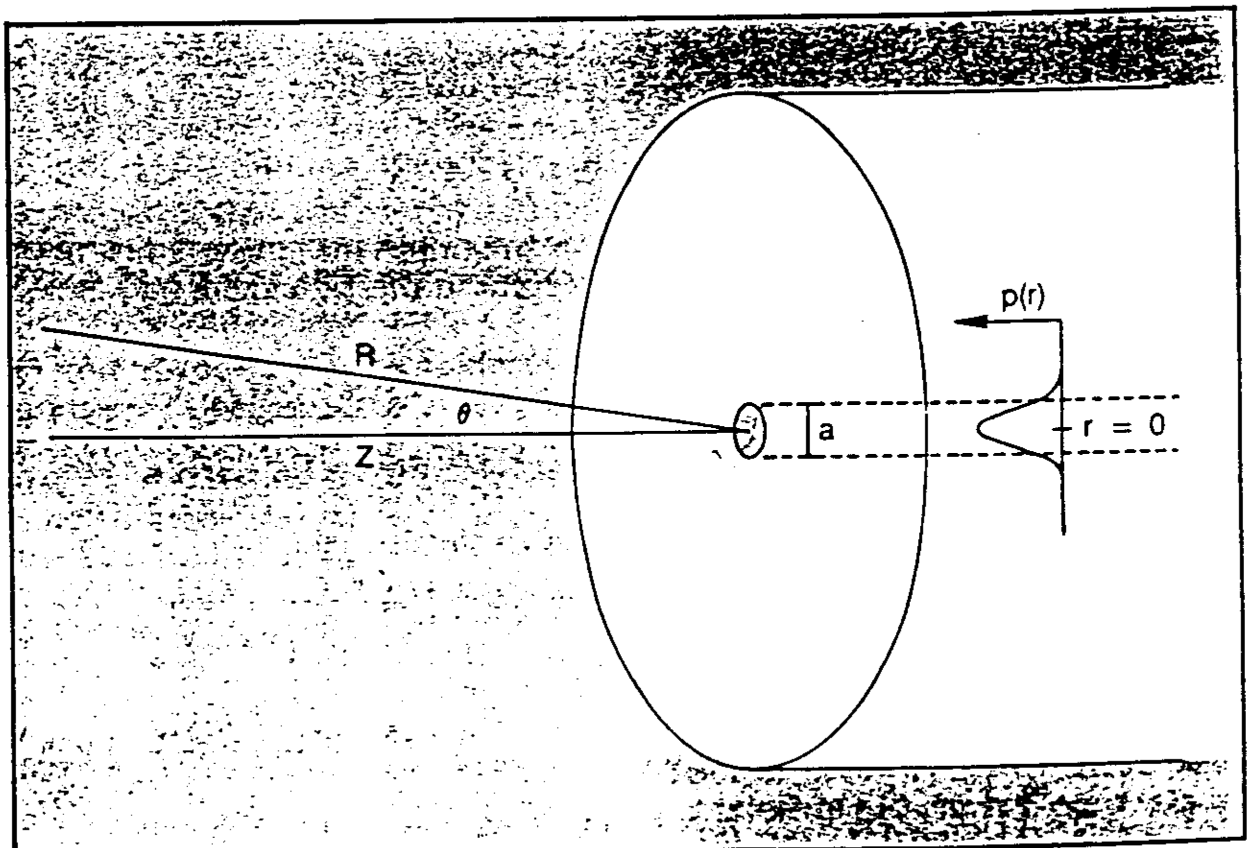

Figure 1. The distribution of light in a singlemode fiber above its cutoff wavelength is represented by p(r).

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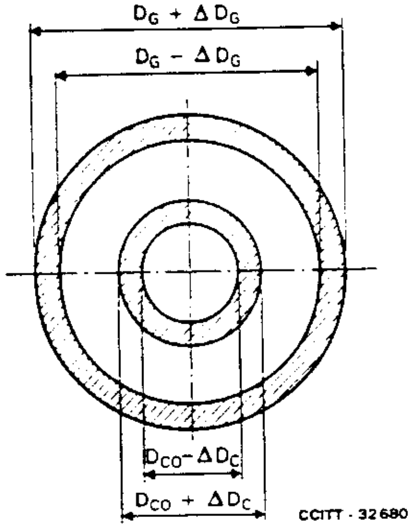


D_{CO}	Diamètre nominal du cœur
ΔD_{CO}	Tolérance applicable au cercle circonscrivant le cœur = 4 µm
D_G	Diamètre nominal de la gaine
ΔD_G	Tolérance applicable au cercle circonscrivant la gaine = 5 µm

FIGURE B-1/G.651

B.1.1.2 *Facteur de qualité intrinsèque*

Les valeurs de l'ouverture maximale théorique, du diamètre du cœur, de l'erreur de concentricité et de la non-circularité du cœur varient simultanément avec soit des effets additionnels, soit des effets compensatoires. Pour tenir compte de façon appropriée de ces effets, une perte théorique due à l'épissurage peut être calculée, en utilisant les valeurs des paramètres géométriques et optiques mesurées par les méthodes existantes. On peut alors définir soit une distribution de Gauss, soit une répartition en régime permanent. Le facteur de qualité intrinsèque (FQI) peut être calculé comme étant la moyenne des pertes théoriques par épissurage dans les deux directions lorsque la fibre d'essai est épissurée à une fibre nominale présentant un défaut d'alignement nul. Une valeur de la FQI de 0,27 dB est compatible avec les tolérances individuelles recommandées dans la section 1 de la Recommandation G.651. Si des différences apparaissent entre la méthode FQI et le contrôle des caractéristiques individuelles, cette dernière série constituera la référence.

B.1.2 *Caractéristiques géométriques*

Le diamètre du cœur et le diamètre de la gaine de la fibre mesurée, ainsi que le centre du cœur et le centre de la gaine, peuvent être déterminés à partir d'un nombre approprié de points convenablement répartis, respectivement sur l'interface cœur/gaine et sur la superficie de la gaine.

Si on adopte une technique d'exploration par balayage, il faut choisir un plus grand nombre de points, pour assurer une répartition suffisamment régulière.

On peut évaluer l'erreur de concentricité à partir de la distance entre le centre du cœur et le centre de la gaine.

La non-circularité du cœur et celle de la gaine peuvent être déterminées à partir du champ de tolérance.

B.2 *Méthodes de mesure de référence pour les paramètres géométriques et méthode de mesure de remplacement pour l'ouverture numérique: technique d'exploration du champ proche réfracté*

B.2.1 *Considérations générales*

La mesure d'exploration du champ proche réfracté est simple, précise et donne directement la variation de l'indice de réfraction dans toute l'étendue de la fibre (cœur et gaine). Elle peut offrir une bonne résolution et être étalonnée de façon à donner des valeurs absolues de l'indice de réfraction.

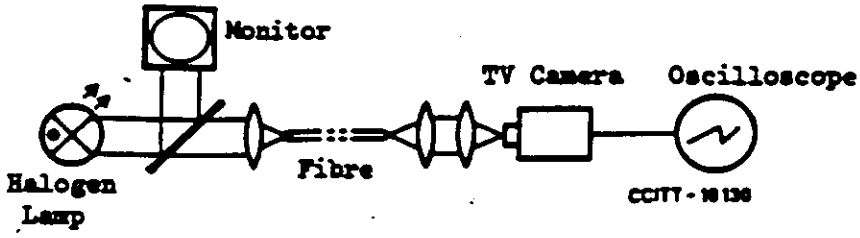
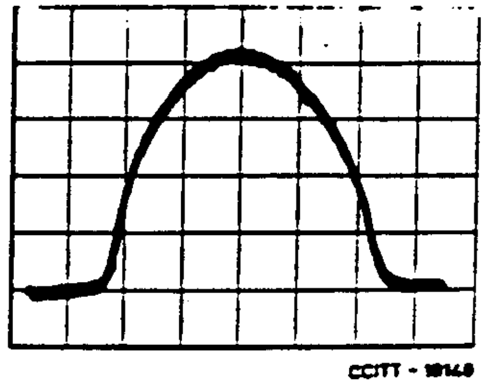


Figure 6 - NFP method block diagram



Annex : 1

(710)

Figure 7 - Graded-index fibre NFP

Geometrical parameters

Core and cladding diameters
Core and cladding concentricity
Core and cladding ellipticity

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+---------------------------+
|contour lines              |
+---------------------------+
```

Experiment : COST 217 WG2

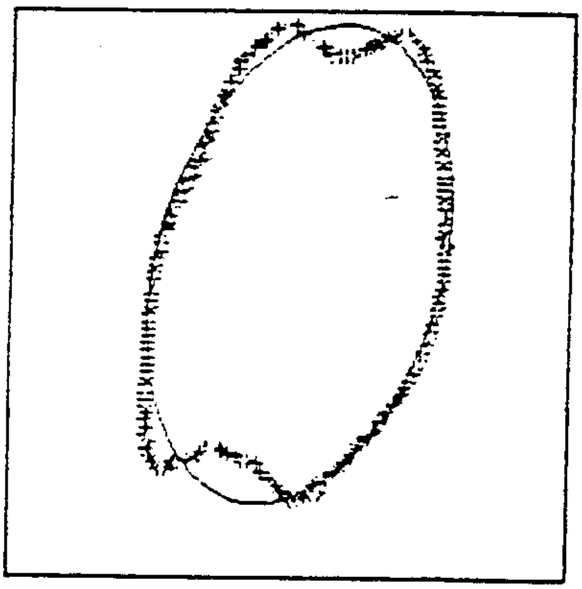
Experiment number: 4

Fibre Name : YORK PM

Comment :

unit = micron N(R) = 1.46357 % = 50.0

Elliptic fit: large axis = 6.92 small axis = 4.10
non circularity = 51.19 %
center X = 4.10 Y = 4.43
standard deviation = 0.31



easurement done the 27-9-89 by GAP UNIVERSITY OF GENEVA, PS

Figure 1 b.

Experiment : COST 217 WG2

Experiment number: 2

Fibre Name : YORK PM

Comment :

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+----------------------------+
!"3d" drawing:               !
+----------------------------+
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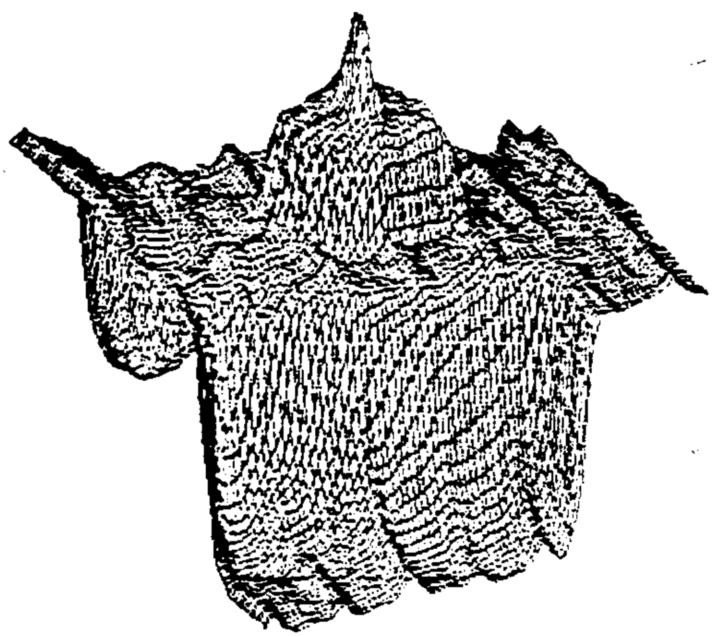
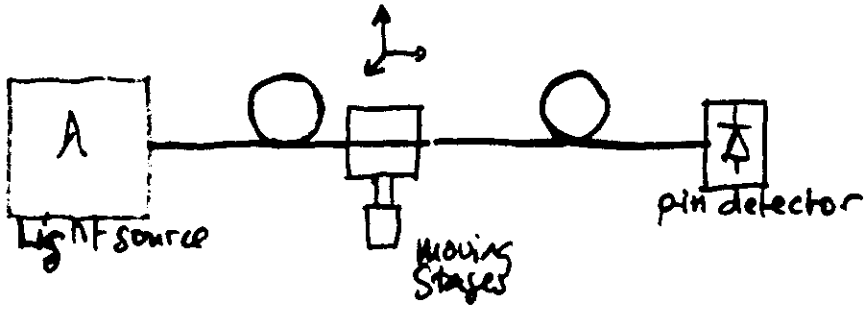


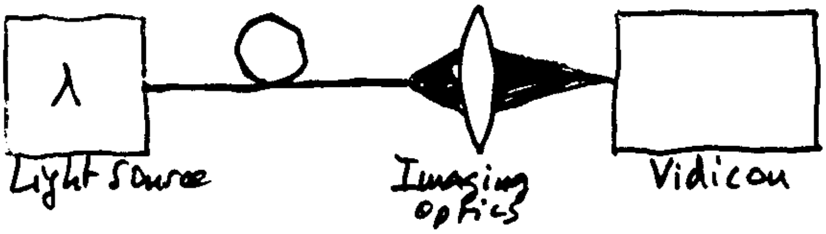
Size in X: 24.0 [mu]   Step in X: 0.3 [mu]
Size in Y: 24.0 [mu]   Step in Y: 0.3 [mu]

Measurement done the 27-9-89 by GAP UNIVERSITY OF GENEVA, PS

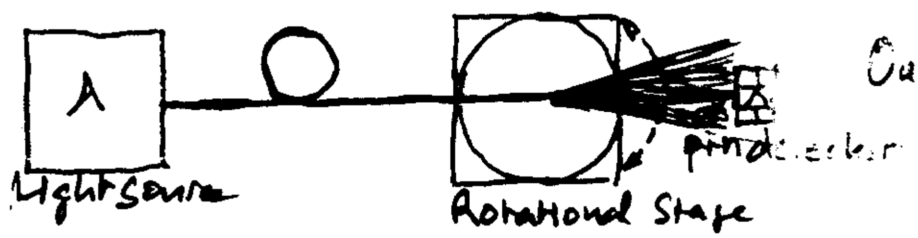
Figure 1 a.



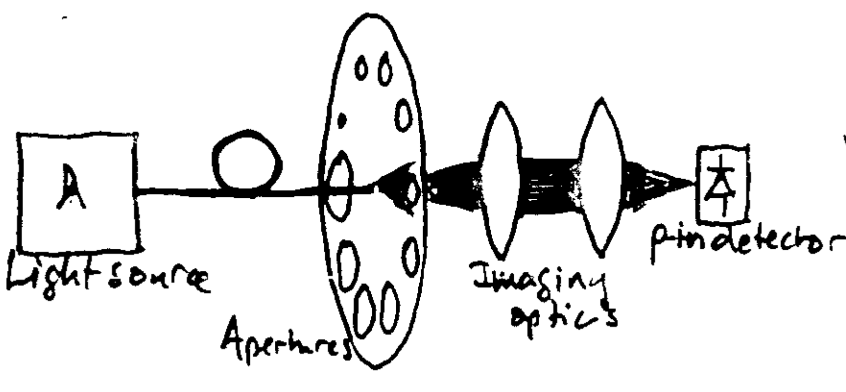
Transverse offset measurement technique



Transmitted near field measurement



One dimensional far-field scanning



Variable aperture method in the far field.

near field : Approximate gaussian intensity

$$P(r) = p_0 \exp -2\left(\frac{r}{W_0}\right)$$

W_0: $1/e^2$ width of the gaussian power distribution.

far field : $P(q) = P_0 \exp -2\left(\frac{q}{W_0}\right)$ $\quad q = \frac{1}{\lambda}\sin\theta$

Peterman distribution of power : non gaussian spot

Systems Division

111, ch. du Pont-du-Centenaire - 1228 PLAN-LES-OUATES / Genève
Tél. 022/71 25 55 - Télex 422 989 opg ch - Fax 022/71 34 69

spot-size

Cable:

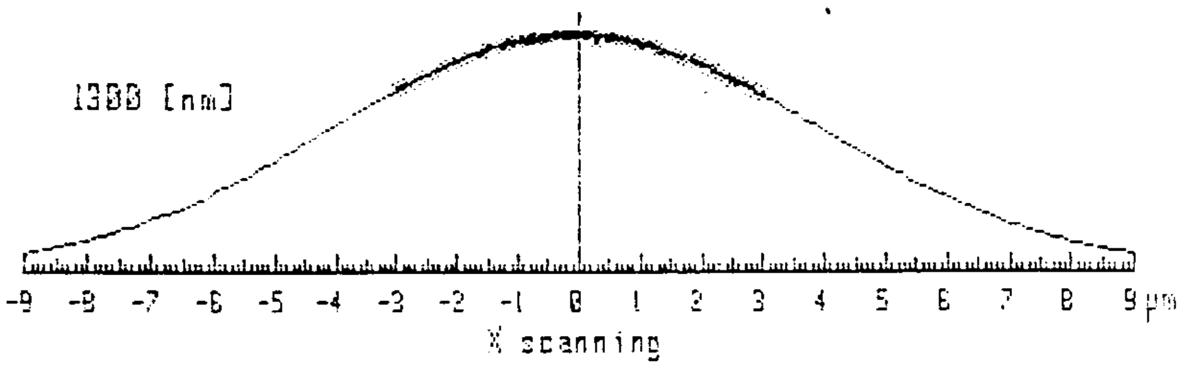
Fiber: 5

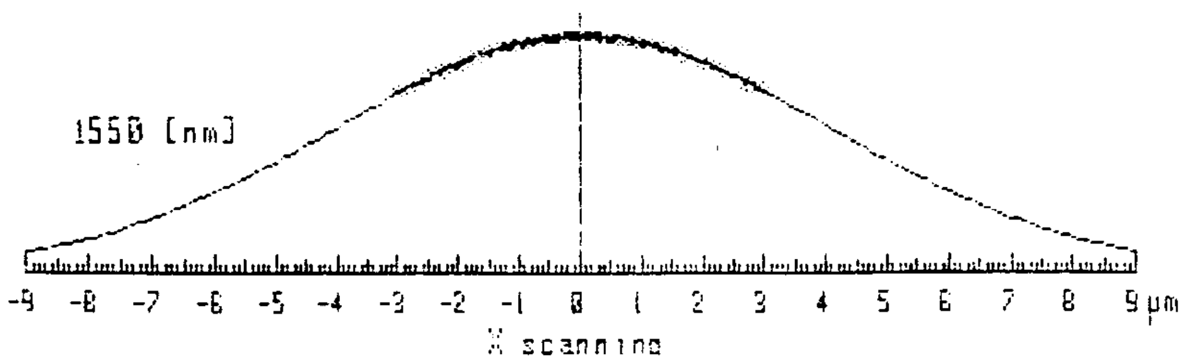
Comment: TEST

Gaussian Fit

Spot-size at: 1300 [nm] = 11.29 [micron] (+- 0.2 %)

Spot-size at: 1550 [nm] = 11.53 [micron] (+- 0.1 %)





Systems Division

111, ch. du Pont-du-Centenaire - 1228 PLAN-LES-OUATES/Genève
Tél. 022/71 25 55 - Télex 422 989 opg ch - Fax 022/71 34 69

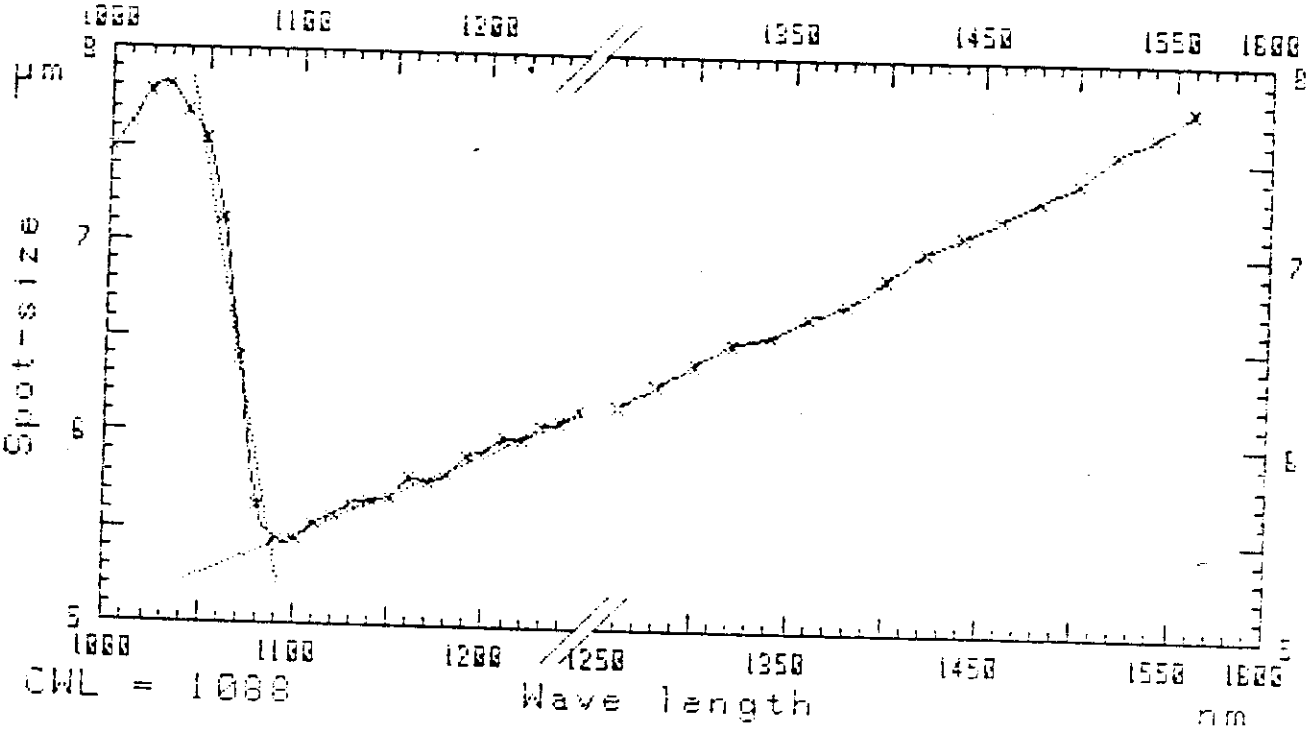
spot-size

Cable: S-4

Fiber: 5

Comment: ZERO DISPERSION 1499nm

Spot-size at: 1300 [nm] = 6.39 [mic]



Measurement done the 19-8-86 by JFW

only the lowest-order mode (straight path) can be excited, thus eliminating mode dispersion completely. The other alternative is to use a light source with a narrow spectral width, such as a laser diode, so as to minimize the material and waveguide dispersions. Another approach is to operate within a wavelength region where the first and second terms of (13.13) cancel each other. For instance, with a single-mode fiber made of fused silica, the first term changes sign near 1.27 μm and the dispersion effect is significantly reduced.

13.4 Fiber Transmission Loss Characteristics

The causes of attenuation in an optical fiber can be broadly grouped into material-related and structure-related areas [12.3, 4]. First, the material-related causes are described. Typical curves of the dependence of fiber loss on wavelength are shown in Fig. 13.4. The curves are approximately V-shaped, and can be divided more or less into four regions according to the attenuation mechanisms which are

i) Rayleigh scattering loss,
ii) OH^- ion absorption loss,
iii) inherent absorption loss,
iv) impurity absorption loss.

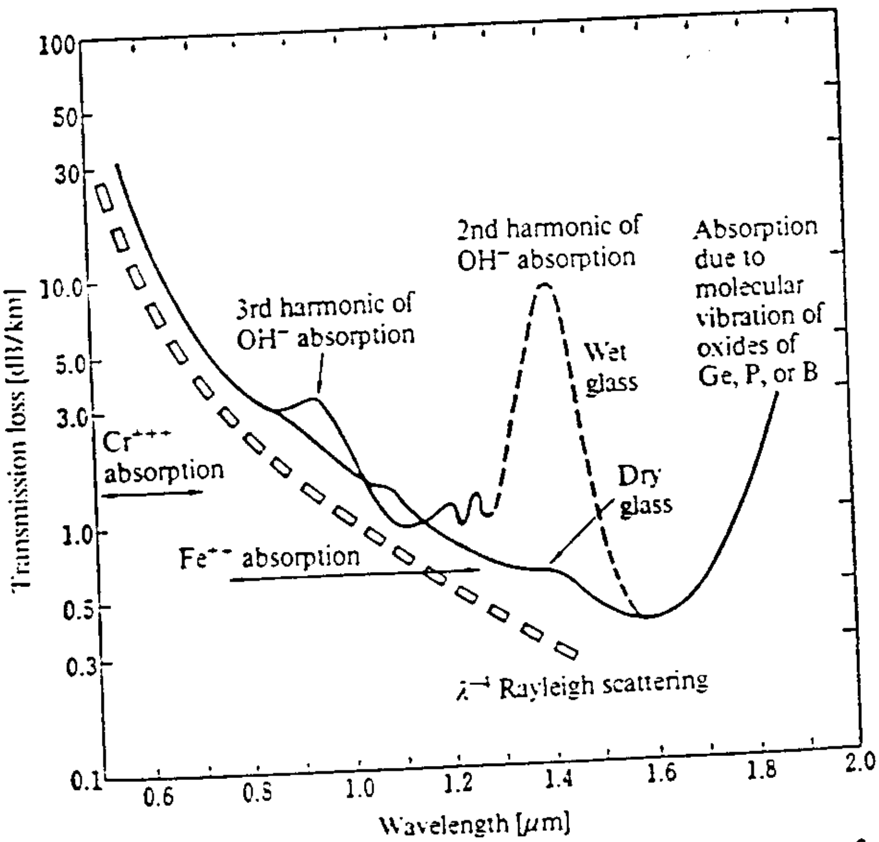
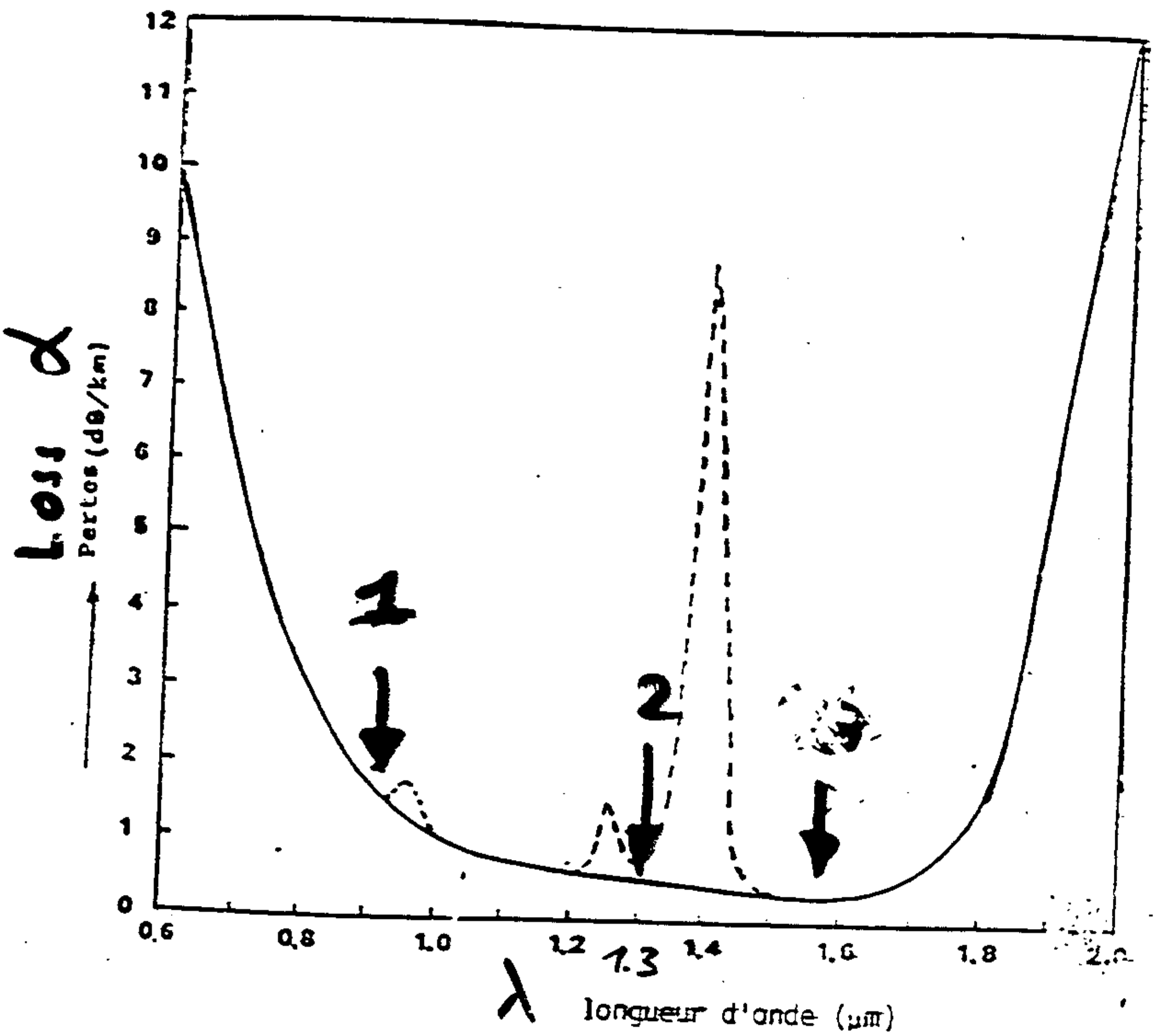
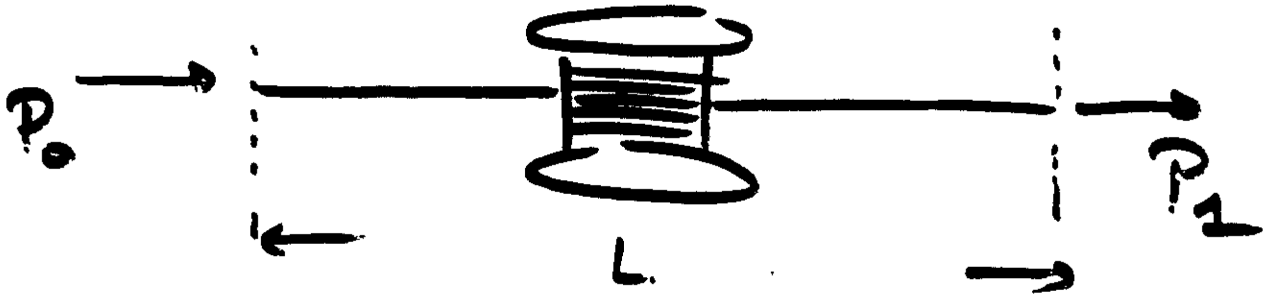


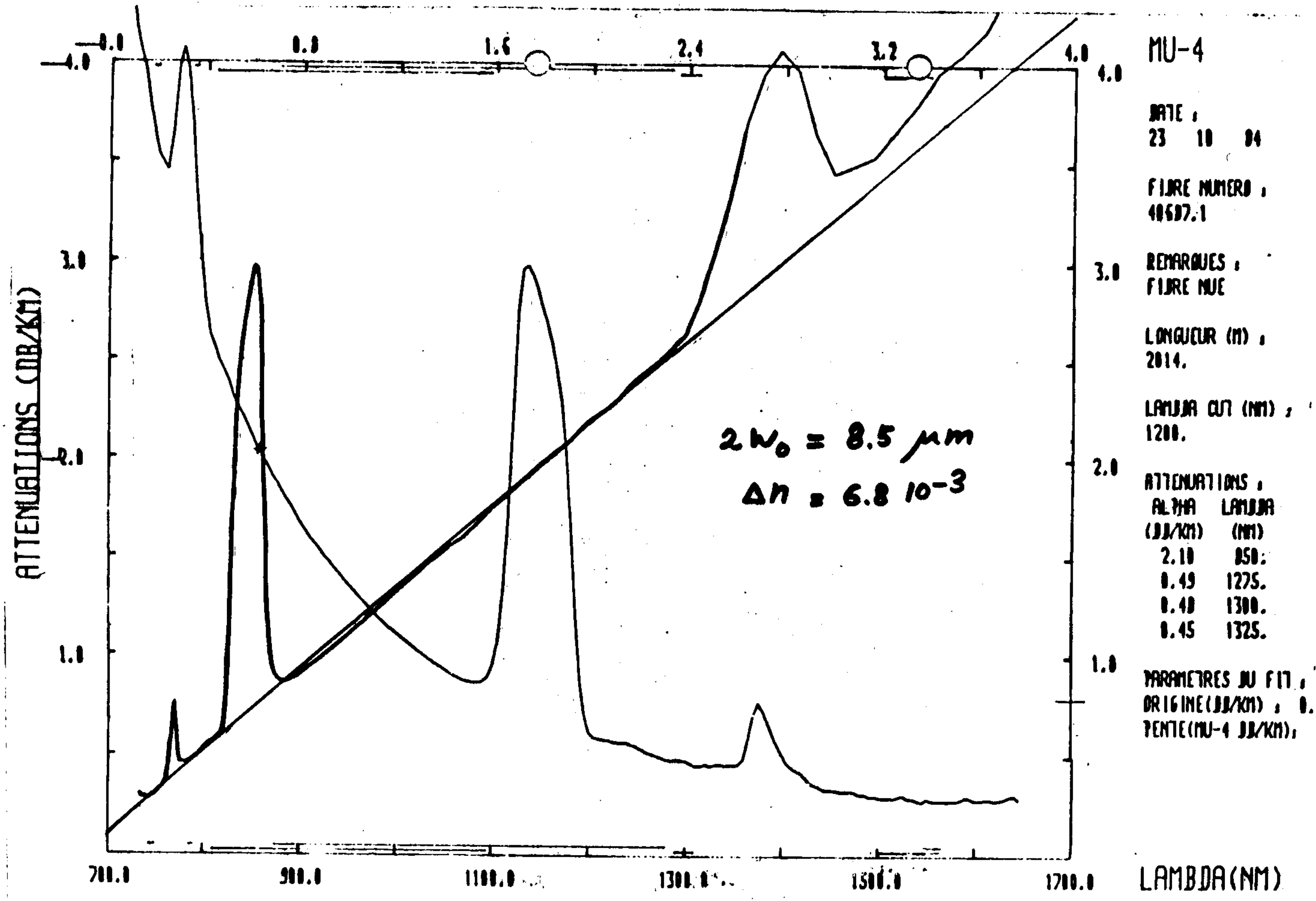
Fig. 13.4. Attenuation characteristics of a fiber as a function of wavelength



$$\alpha(\lambda) = \frac{1}{L} 10 \log \frac{P_0}{P_1}$$

[dB/km]




MU-4
DATE :
23 10 84
FIBRE NUMERO :
40607.1
REMARQUES :
FIBRE NUE
LONGUEUR (M) :
2014.
LAMBDA CUT (NM) :
1200.
ATTENUATIONS :
ALPHA LAMBDA
(DB/KM) (NM)
2.10 850.
0.49 1275.
0.40 1300.
0.45 1325.
PARAMETRES DU FIT :
ORIGINE(DB/KM) : 0.
PENTE(MU-4 DB/KM):
ATTENUATIONS (DB/KM)
LAMBDA(NM)
700.0
900.0
1100.0
1300.0
1500.0
1700.0
1.0
2.0
3.0
4.0
0.0
0.8
1.6
2.4
3.2
$2w_0 = 8.5\ \mu m$
$\Delta n = 6.8\ 10^{-3}$

B.4.3.2.2 *Source optique*

Il convient d'utiliser une source optique stable de forte puissance et d'une longueur d'onde appropriée. La longueur d'onde de la source doit être enregistrée. La durée et le taux de répétition des impulsions doivent être compatibles avec la résolution voulue et la longueur de la fibre. Il convient d'éliminer les effets optiques non linéaires à l'accès de la fibre à mesurer.

B.4.3.2.3 *Dispositif de couplage*

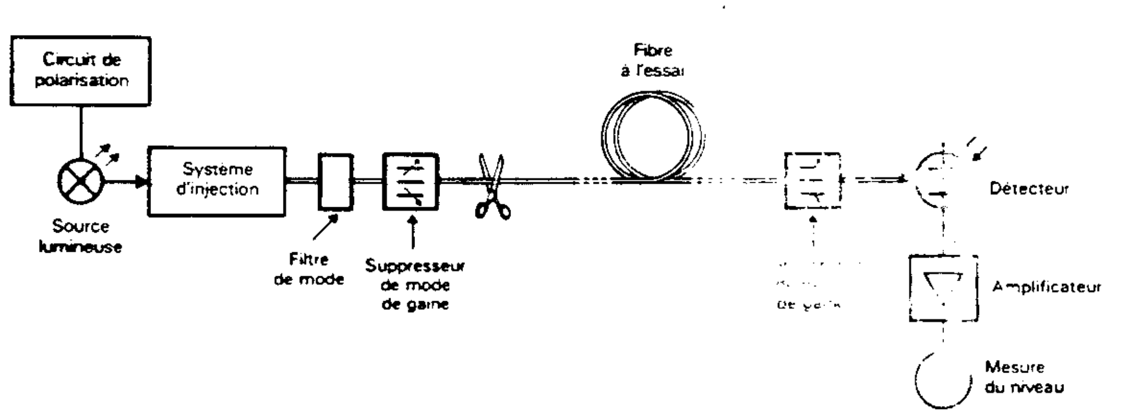
Il faut utiliser un dispositif de couplage pour coupler le rayonnement incident de la source à la fibre et le rayonnement rétrodiffusé au détecteur, tout en évitant un couplage direct source-détecteur. On peut utiliser plusieurs types de dispositifs mais les dispositifs basés sur des effets de polarisation sont à éviter.

B.4.3.2.4 *Détecteur optique*

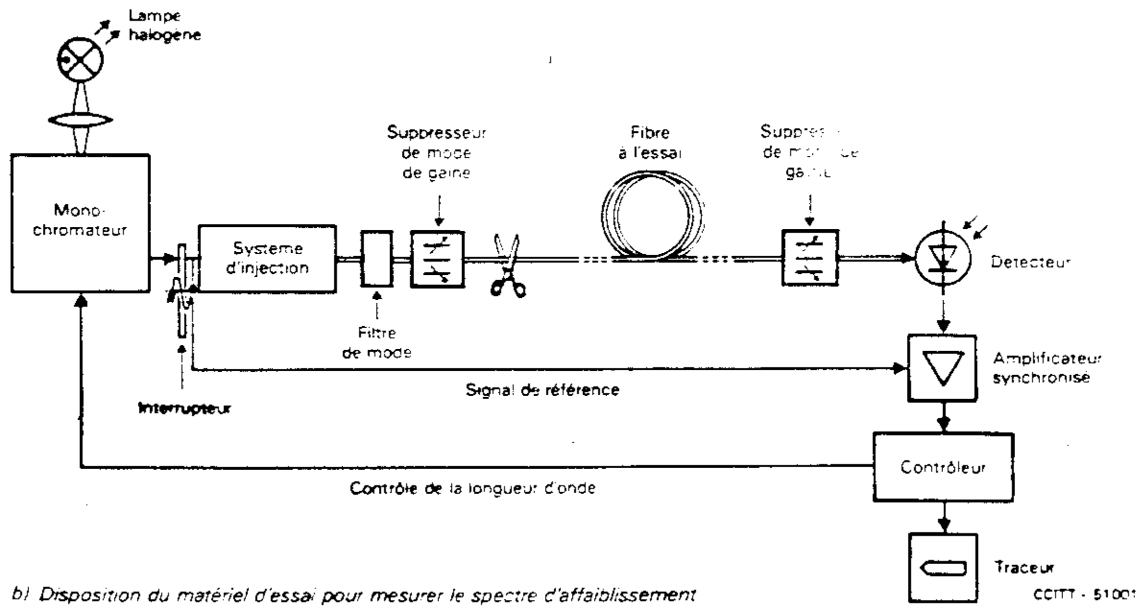
On utilisera un détecteur afin d'intercepter la plus grande partie possible de la puissance rétrodiffusée. La réponse du détecteur doit être compatible avec les niveaux et les longueurs d'onde du signal détecté. Pour la mesure de l'affaiblissement, la réponse du détecteur doit être suffisamment linéaire.

Le traitement du signal est nécessaire pour améliorer le rapport signal/bruit, et il est souhaitable que la réponse du système de détection soit logarithmique.

Un amplificateur approprié doit suivre le détecteur optique, afin que le niveau du signal soit suffisant pour le traitement du signal. La largeur de bande choisie pour l'amplificateur doit représenter un compromis entre résolution temporelle et réduction de bruit.



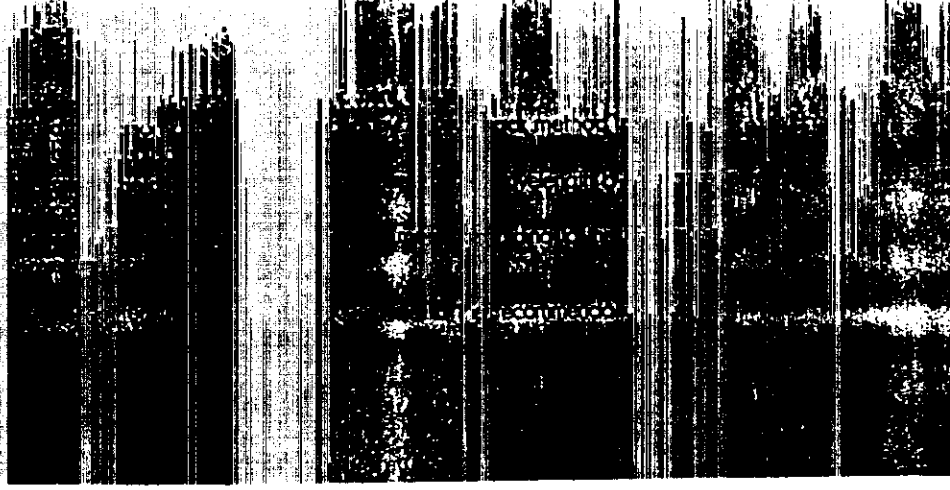
a) Disposition du matériel d'essai pour mesurer un affaiblissement



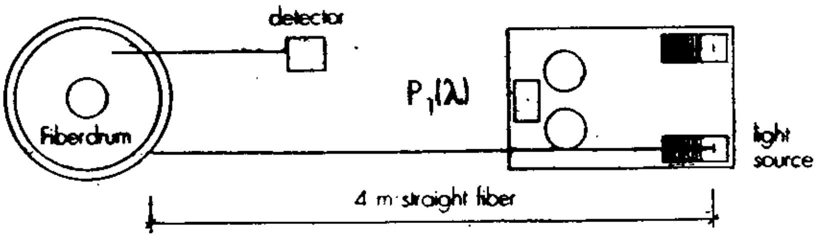
b) Disposition du matériel d'essai pour mesurer le spectre d'affaiblissement

FIGURE B-9/G.652

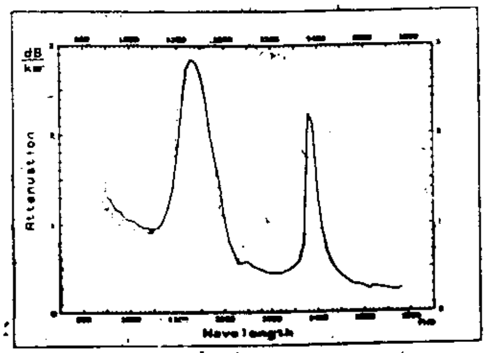
Technique de la fibre coupée



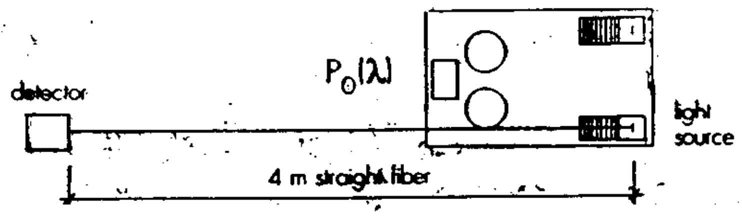
METOSA

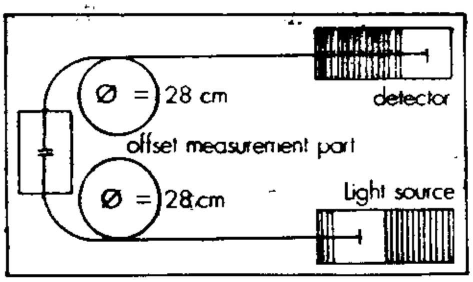


$$\alpha(\lambda) = \frac{10}{L_1 - L_0} \, \text{Log} \, \frac{P_1(\lambda)}{P_0(\lambda)}$$

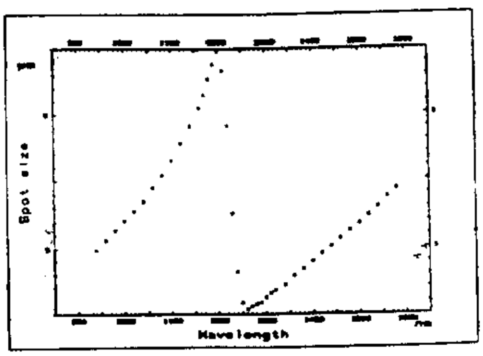


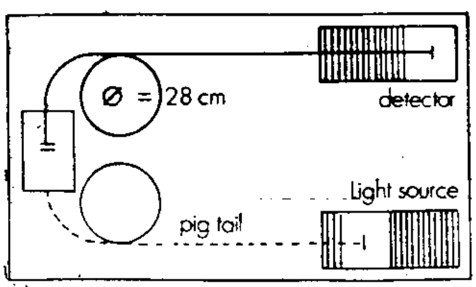
ATTENUATION: [α]
(cut back method)



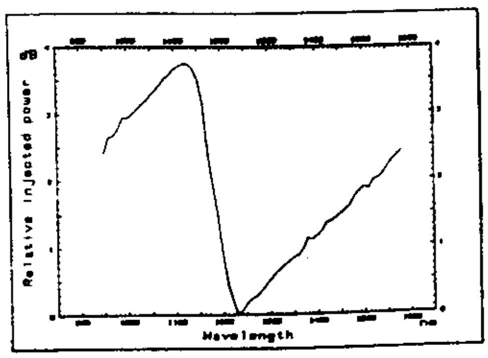


MFD (CWL)
(transverse offset method)

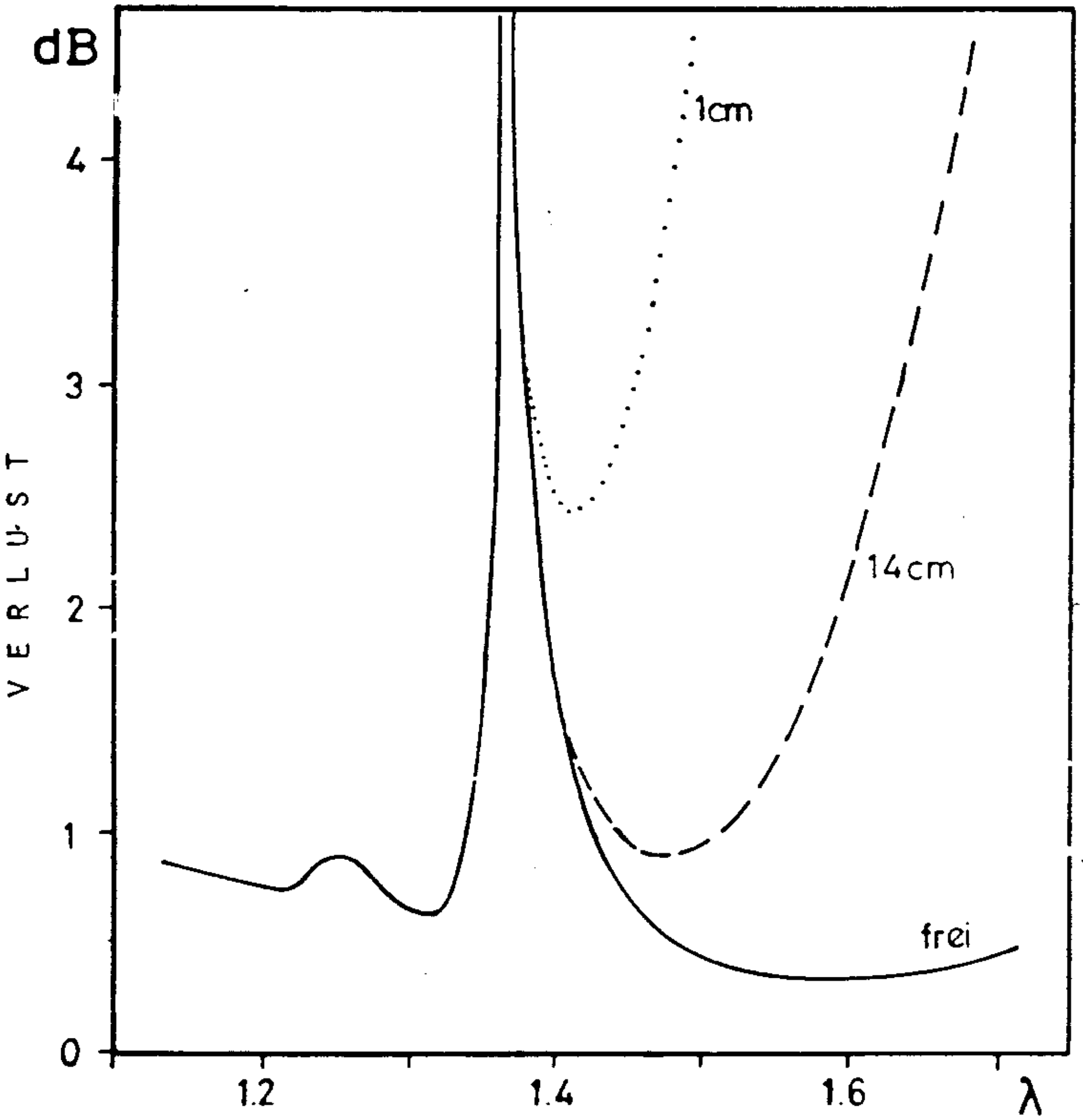




CWL of LP_{11} mode
(transmitted power method)



BIEGUNG EFFEKT



attenuation

Cable: E14228 - 1

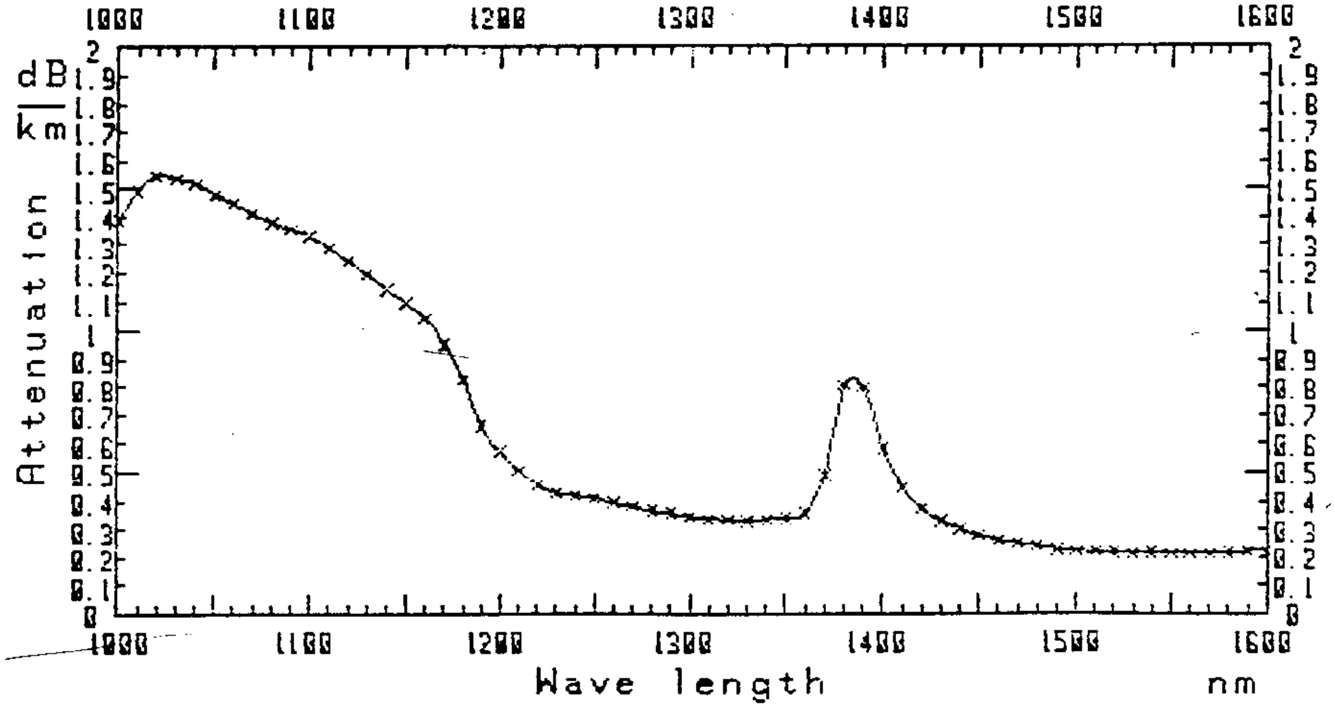
Fiber: 6

Comment:

Fiber length: 6452 [meters]

Attenuation at: 1300 [nm] = 0.34 [dB/km]

1550 [nm] = 0.21 [dB/km]



Measurement done the 20-08-87 by

OPG ELECTRONICS SA
Systems Division
111, ch. du Pont-du-Centenaire - 1228 PLAN-LES-OUATES / Genève
Tél. 022/71 25 55 - Télex 422 989 opg ch - Fax 022/71 34 69

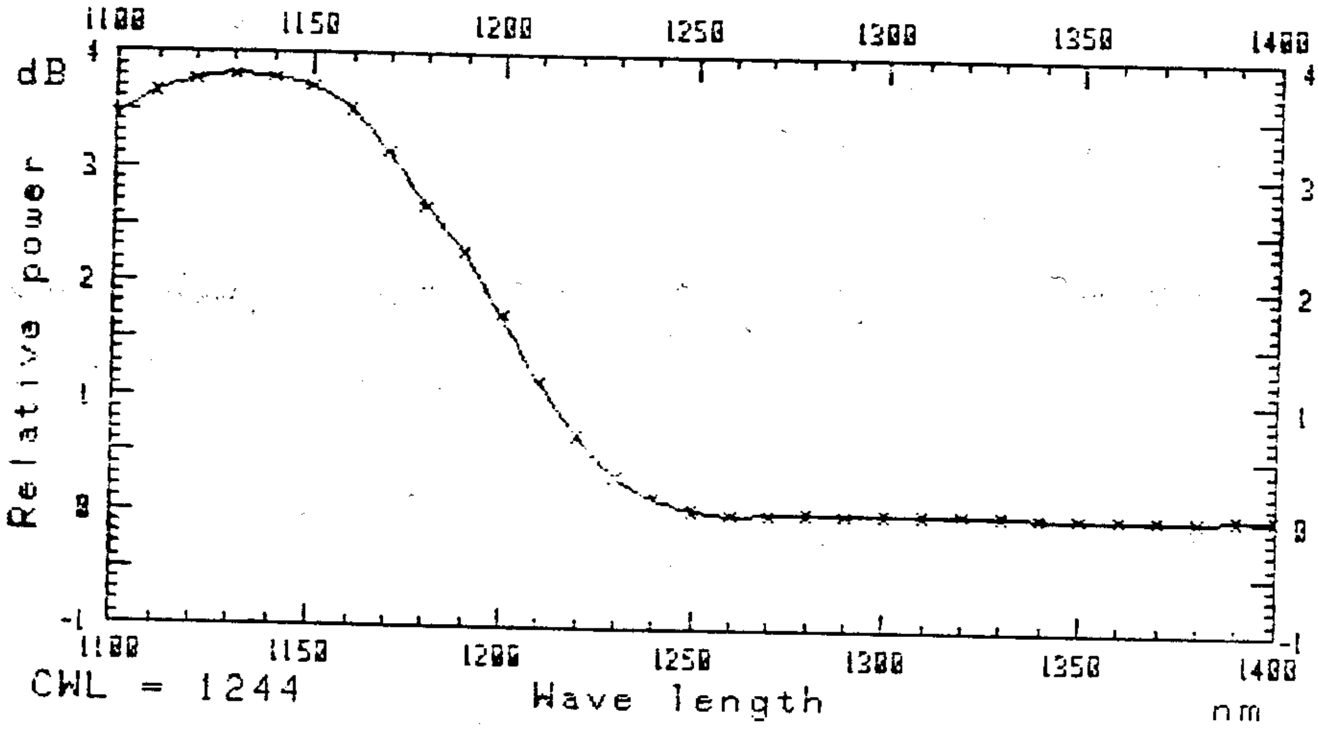
CWL

Cable: RU10

Fiber: 1

Comment:

Cut off wave length : 1244[nm]



Measurement done the 24-10-86 by CM NG

Plan

I Introduction to the fiber optical communication.

1 Evolution from the technology of multimode fibers to single mode fibers

2. Description of the single mode fiber

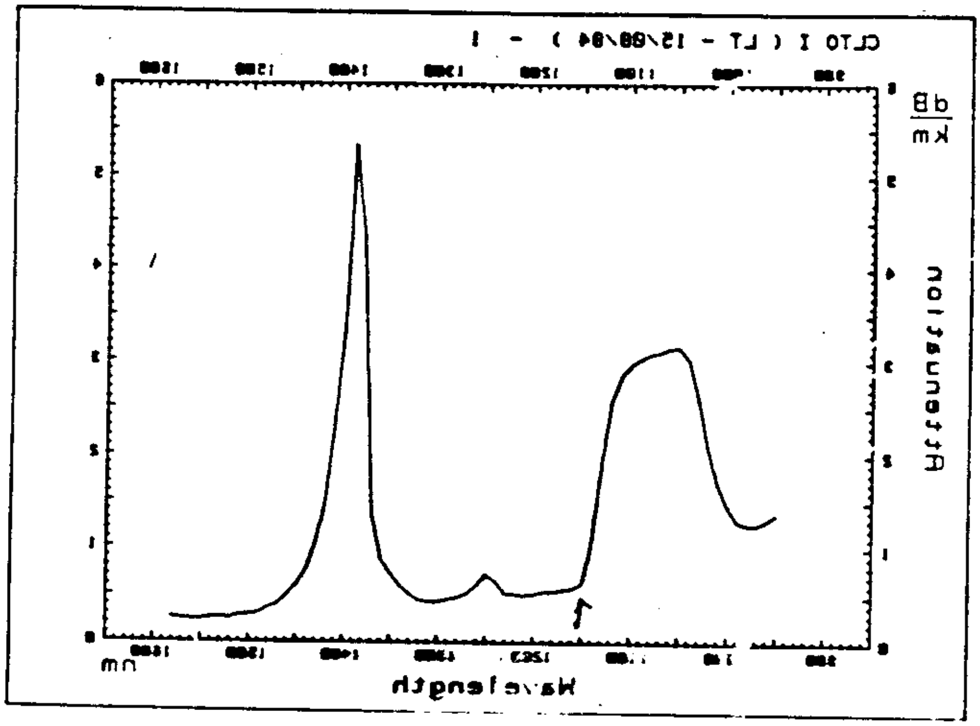
3. Optical fiber fabrication

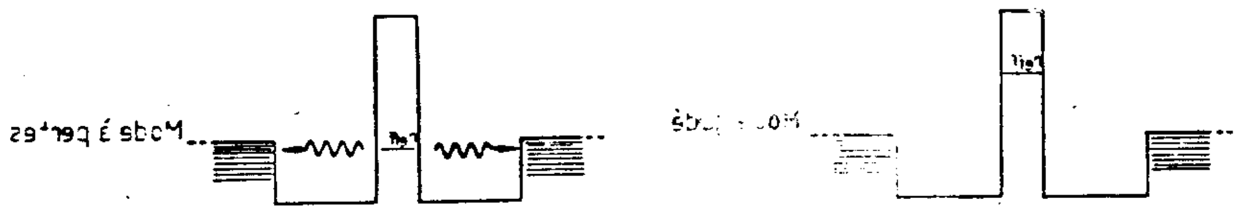
II Characterization

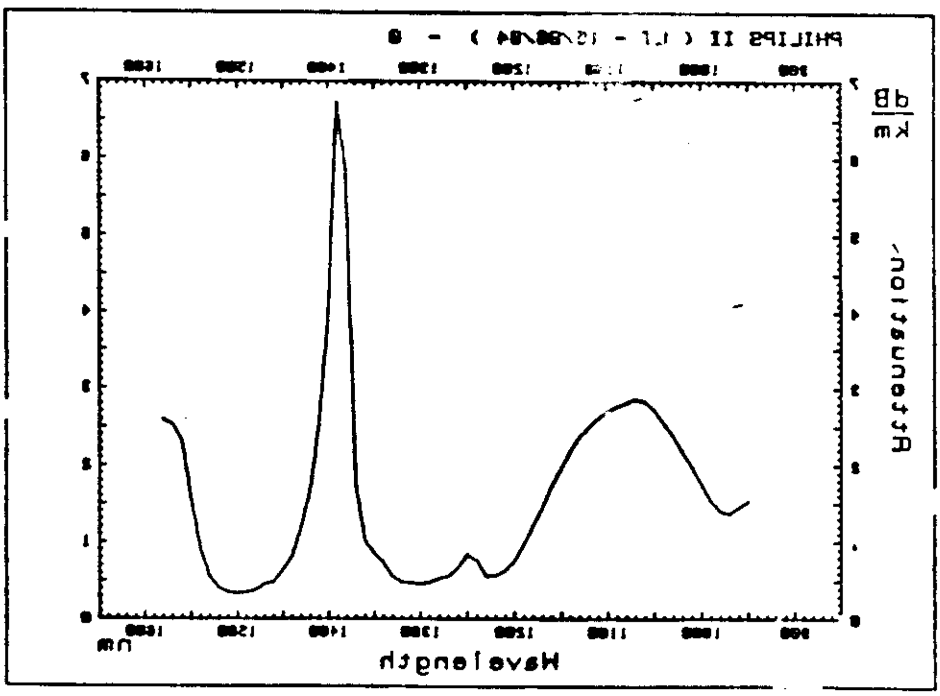
1. Geometry : - Refractive index profile
   - mode field diameter

2. Attenuation
3. Cut'off wavelength
4. Chromatic dispersion
   a) Interferometric method
   b) Phase shift method
5. Birefringence or polarization dispersion

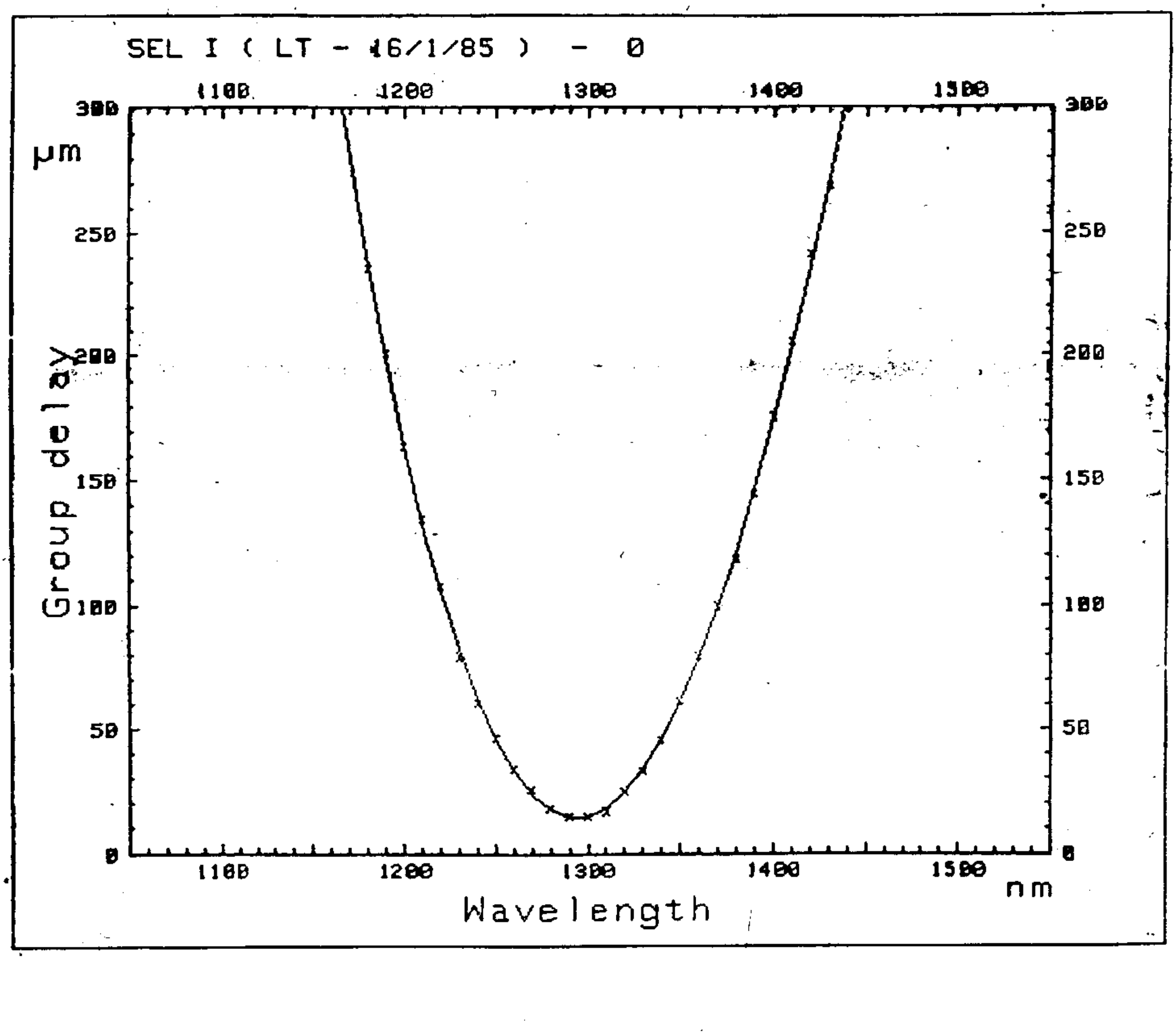
Bibliography : L.B. Jeunehomme
"Single-mode fiber optics"
: K. Iizuka
"Engineering optics"
: T. Okoshi
"[illegible]"


CLTO I (LT - 15/08/84) - 1
dB/km
Attenuation
Wavelength
nm


Mode à pertes
Mode guidé

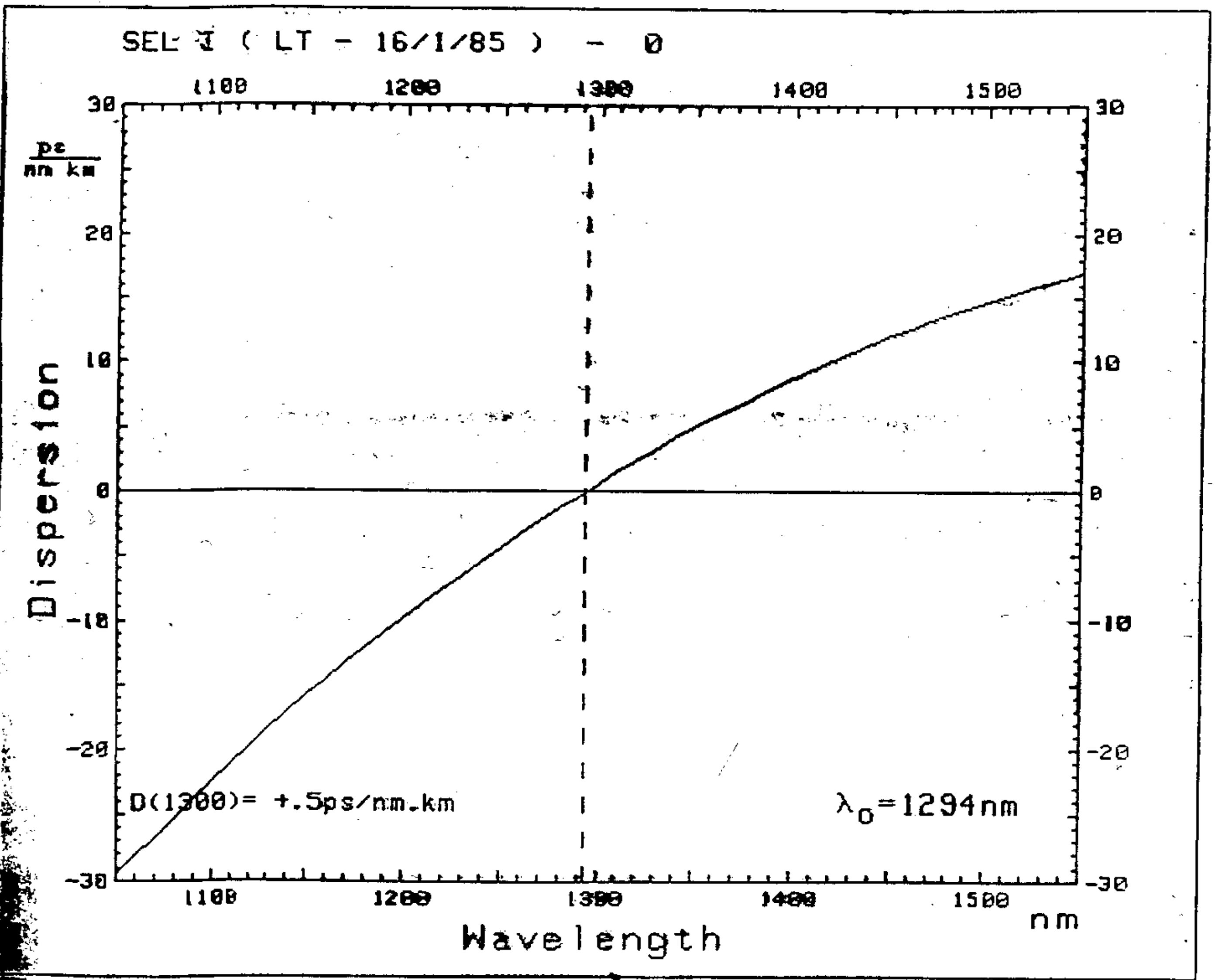

PHILIPS II (LT - 15/08/84) - 8
dB/km
Attenuation
Wavelength
nm

Group delay $\tau(\lambda)$



Chromatic dispersion

$$D(\lambda) = \frac{1}{L}\frac{d\tau}{d\lambda} \; [ps/km, nm]$$



Chromatic dispersion

Causes materiel $n = n(\lambda)$

waveguide $k = k(\lambda)$

In this case:

phase velocity of light

$$V_p = \frac{c}{n(\lambda)}$$

group velocity of light

$$V_g = \frac{d\omega}{dk} = \frac{d(kV_p)}{dk} = V_p + k\frac{dV_p}{dk}$$

$$= V_p + \frac{2\pi}{\lambda}\frac{dV_p}{d\left(\frac{2\pi}{\lambda}\right)}$$

$$\boxed{V_g = V_p - \lambda\frac{dV_p}{d\lambda}}$$

group delay (over L)

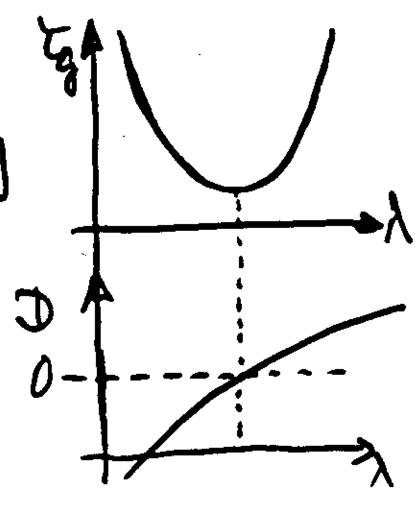
$$t_g = \frac{L}{V_g} \quad (s)$$

group delay by length unit

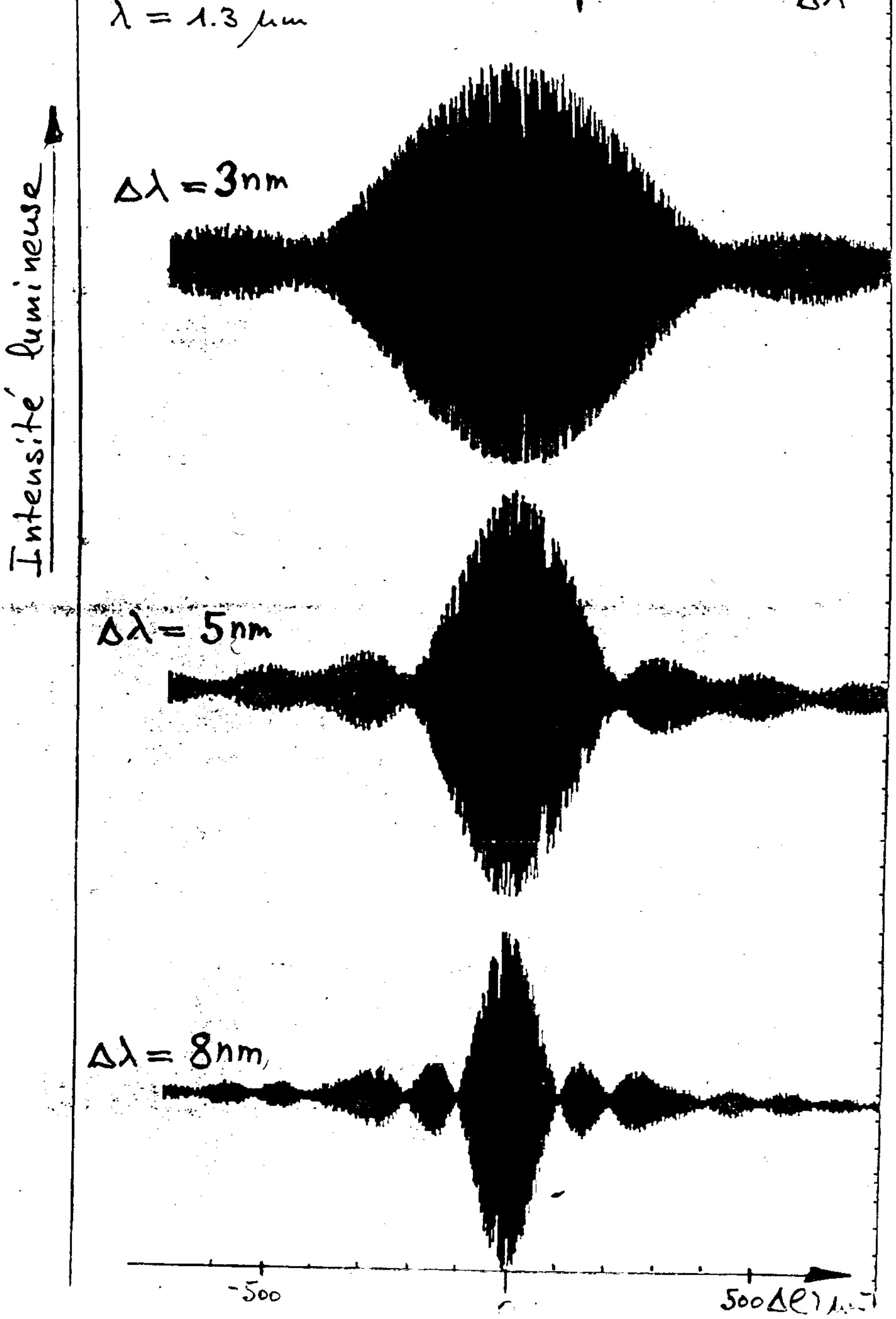
$$\tau_g = \frac{1}{V_g} = \frac{dk}{d\omega} \quad [ps/km]$$

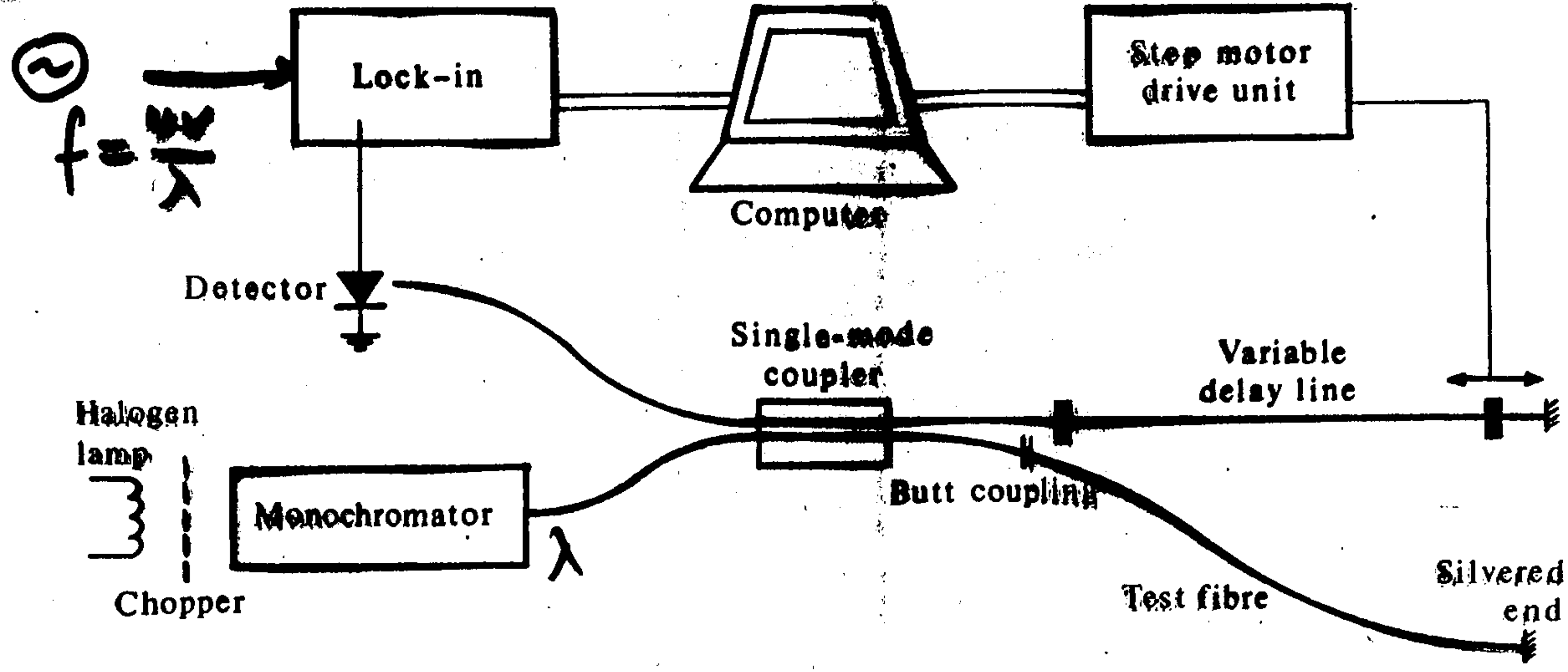
chromatic dispersion

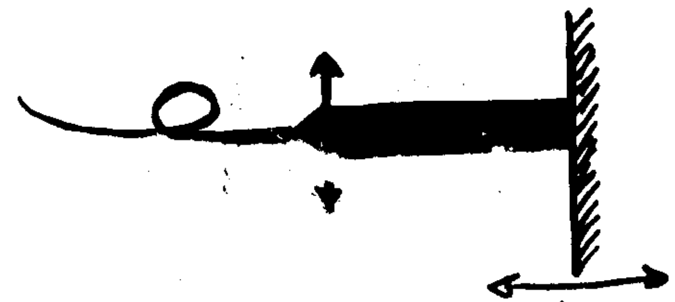
$$\boxed{D = \frac{d\tau_g}{d\lambda}} \quad [ps/km \cdot nm]$$



Coherence temporelle $l_c = \frac{\lambda^2}{\Delta\lambda}$







stepmotor $= 0.1 \mu m$

Time Resolution $0.2 \mu m \times \frac{1}{c} = 7 \cdot 10^{-16}$ sec

$(c = 3 \cdot 10^{14} \mu m/s)$

te de longueurs
directement le
par l'interférence
on directe a pu
ent du paquet
éférence dans le
iée en variant la
tement du paquet
une porteuse –
les interférences
1 de contraste.
revient donc à
ette démodulation
la fréquence de
eux raisonnements

de référence de
r le détecteur,
la vitesse de
longueur d'onde,
ensuite déduite,

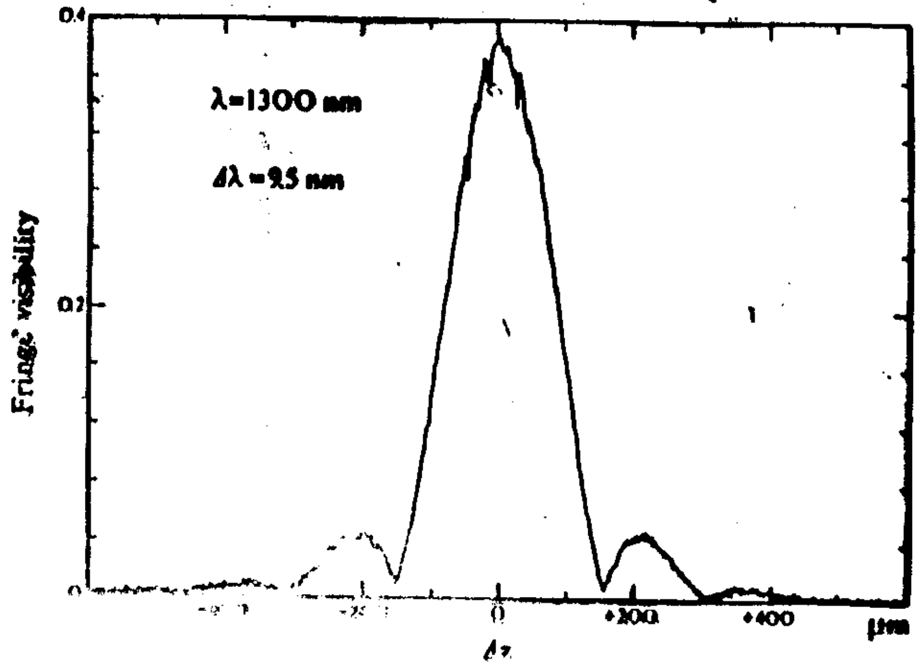
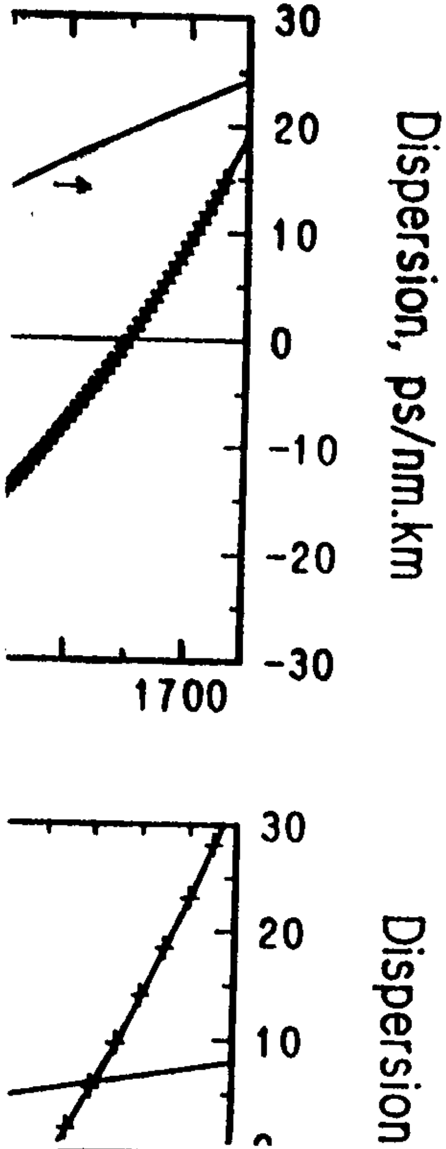


Fig. 4.9 Mesure directe du contraste d'interférence en fonction de la variation de longueur du bras de référence.

configuration expérimentale utilisée, v est égale à 40 µm/s, ce qui donne f = 72 Hz pour λ = 1300 nm. La figure 4.9 représente une telle mesure directe du contraste d'interférence, réalisée en une quinzaine de secondes. La durée d'une mesure devient ainsi tout-à-fait acceptable.

Pour déterminer la position du centre du paquet d'interférences, qui



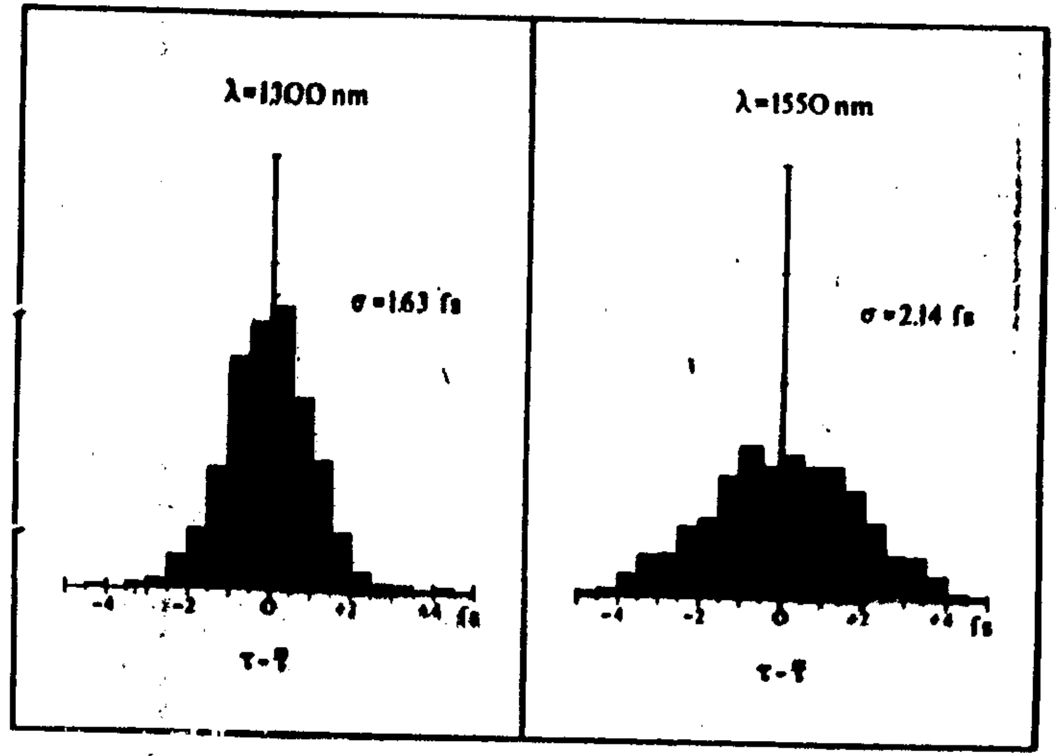


Fig. 4.11 Histogrammes de 1000 mesures du centre du paquet d'interférences pour deux longueurs d'onde typiques, et écarts−type estimés correspondants.

La figure 4.11 représente l'histogramme de la distribution des positions mesurées autour de la moyenne. Aux écarts statistiques mesurés de 1,63 fs à 1300 nm et 2,14 fs à 1550 nm correspondent les résolutions de 0,44 ps/km à

MEASUREMENT TECHNIQUES

Most of the techniques used for characterizing dispersion in single mode fibers are based on the direct measurement of the group delay τ as a function of the wavelength λ. The chromatic dispersion is obtained by differentiation of $\tau(\lambda)$:

$$D(\lambda) = \frac{1}{L} \times \frac{d\tau}{d\lambda}$$

Where L is the length of the light path in the dispersion medium.
Group delay variations by time-of-flight techniques such as pulse delay require fast pulse detection and measurement on fibers that are longer than 5 km. Phase measurement techniques require large signal to noise ratio for accurate phase measurement and have limited dynamic range. Interferometric techniques have demonstrated superior time resolution and can be used to characterize chromatic dispersion on fibers as short as one meter.

MEASUREMENT METHOD: INTERFEROMETRY

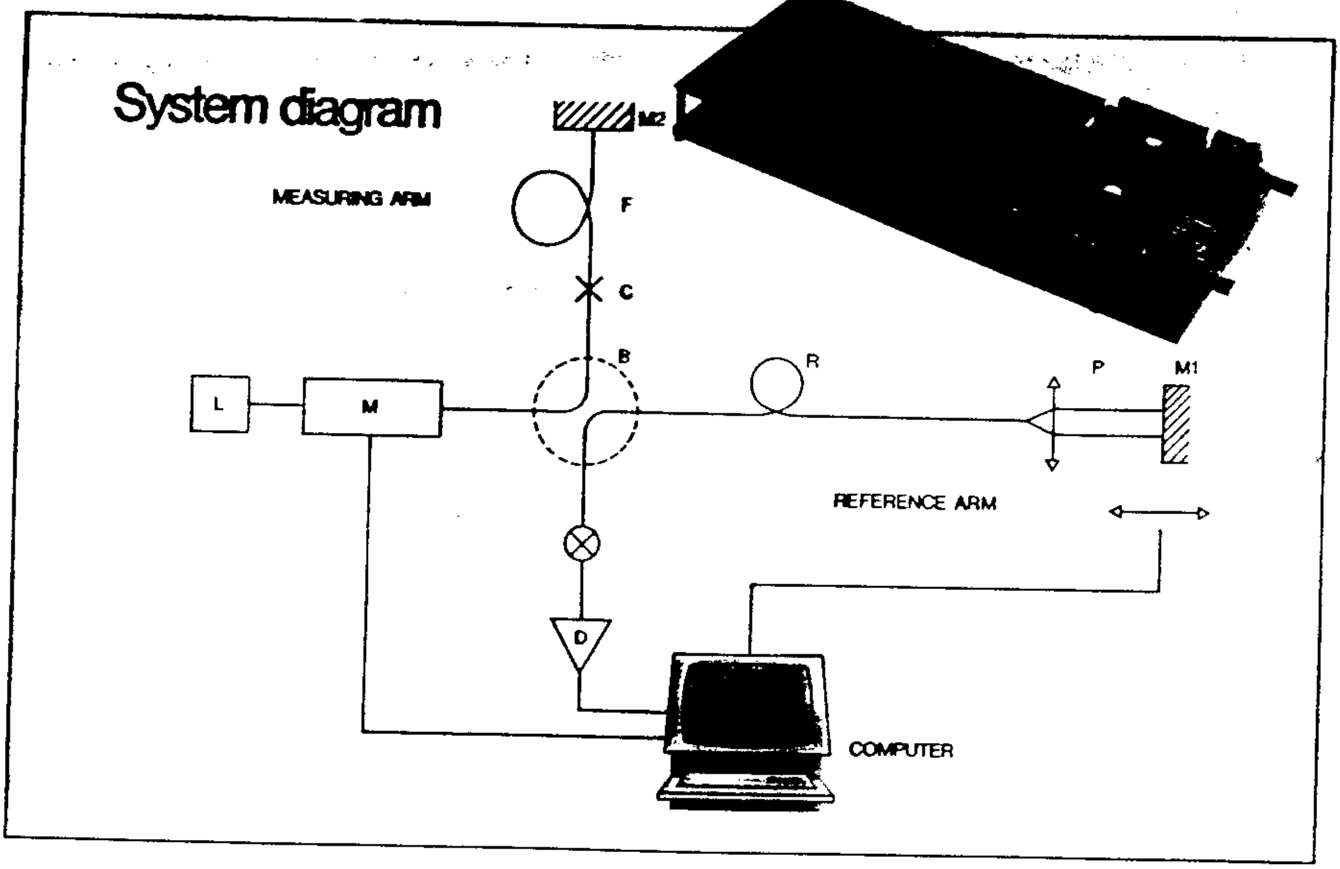
The interferometric method used for measuring the group delay is based on the fact that when limited coherence light is split in the two arms of an interferometer and recombined at the exit of the interferometer, maximum fringes contrast is obtained when the group delays in both arms are equal.

DESCRIPTION OF THE DC 85047

The DC 85047 is a computer controlled workstation which measures the chromatic dispersion of single mode fibers with an interferometric method for group delay measurements. The DC 85047 chromatic dispersion measurement set consists of a MICHELSON interferometer in which the light in the reference arm is scanned by a computer controlled mirror. Fringes contrast is directly measured and the center of the fringes pattern is computed at each selected wavelength λ. The corresponding group delay curve $\tau(\lambda)$ is fitted with polynomial or Sellmeier curve. The chromatic dispersion is obtained by a direct differentiation of the fitted curve.

The DC 85047 consists of a white light source L and a monochromator M that provide an 8 nm wide spectral light in the 1100 to 1700 um range. Light is split into the interferometer arms at B, reflected on mirrors M1 and M2 then detected at detector D. The reference arm contains a single mode fiber R, a variable air path P and a scanning mirror M1. The measuring arm consists of the fiber under test F coupled to the interferometer and to a fixed mirror. A device ensures proper alignment of the fiber at the coupling point.

The Chromatic Dispersion Test Set features a workstation and a fiber sample cutting tool. The workstation is controlled by a computer of the type Hewlett-Packard series 200 or 300, via an IEEE 488 interface bus.
The fiber sample cutting tool allows quick and accurate fiber sample preparation.



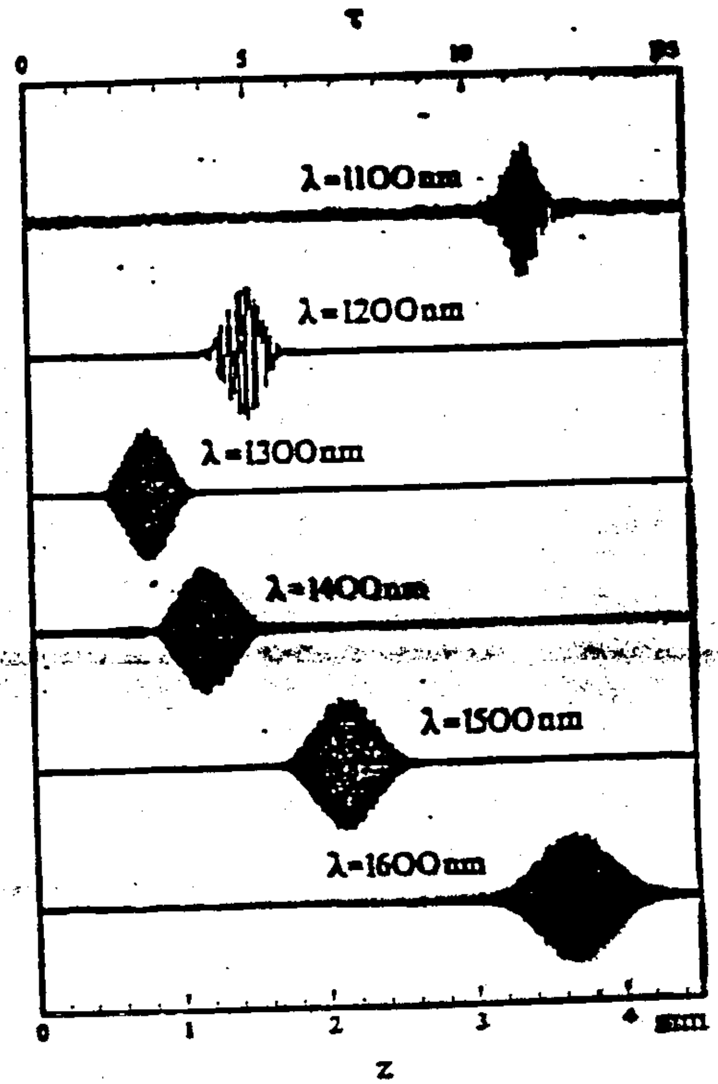

τ
0
5
10
ps
λ=1100nm
λ=1200nm
λ=1300nm
λ=1400nm
λ=1500nm
λ=1600nm
0
1
2
3
4
mm
z

Figure 13

Group delay time $\tau(\lambda)$

Fit by three terms Sellmeier

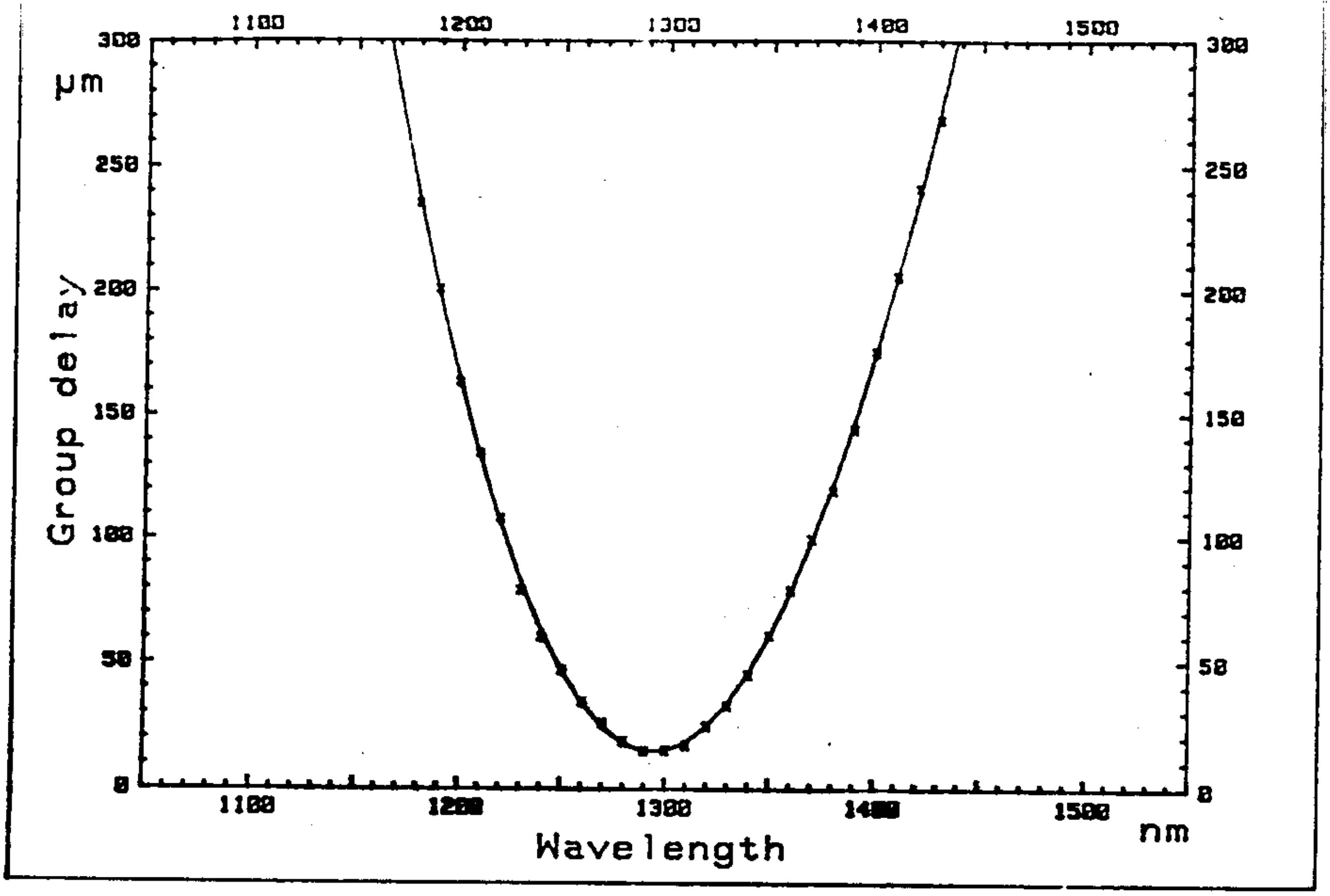
$$\boxed{\tau(\lambda) = c_1\lambda^{-2} + c_2 + c_3\lambda^{2}}$$

or

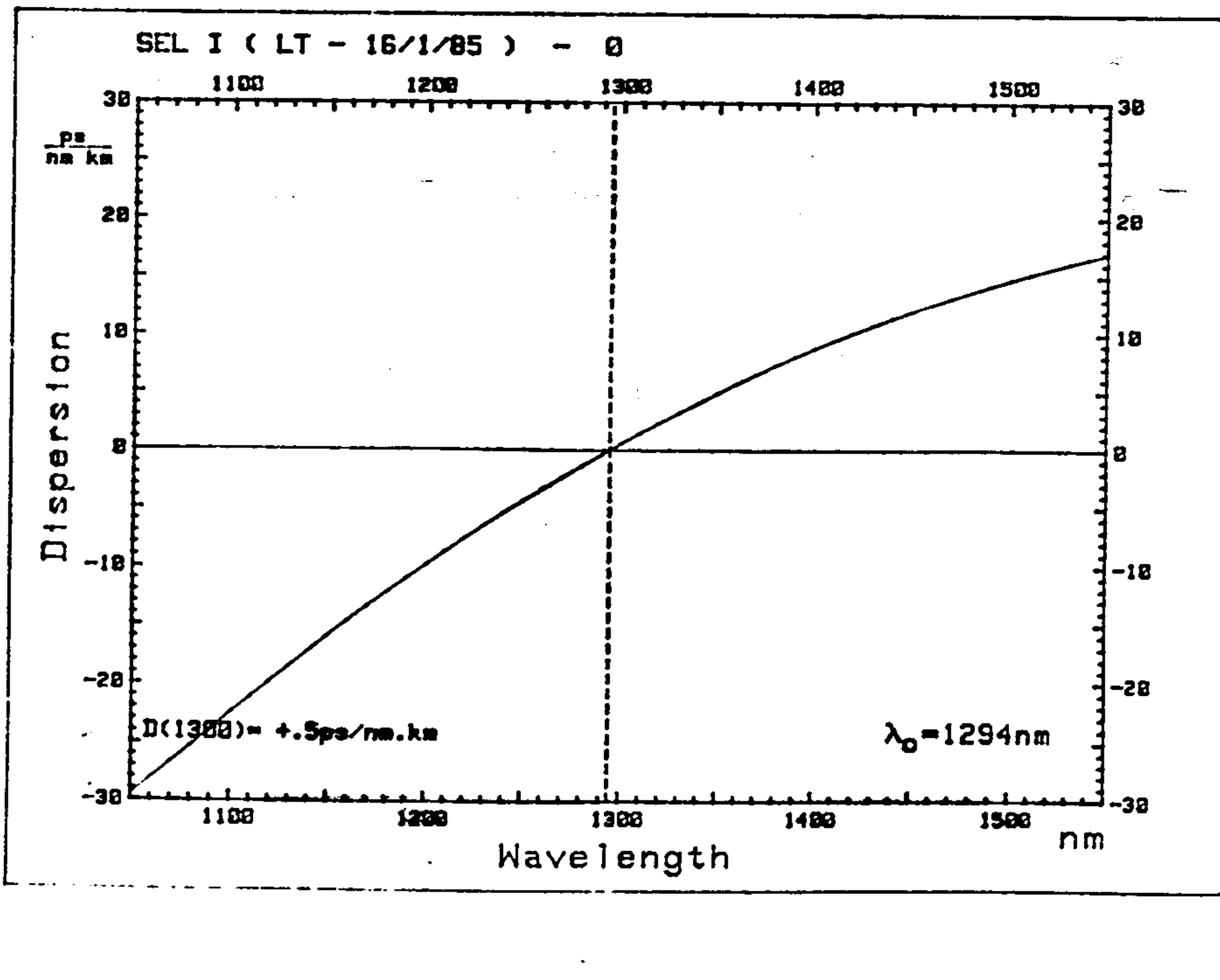
five terms Sellmeier

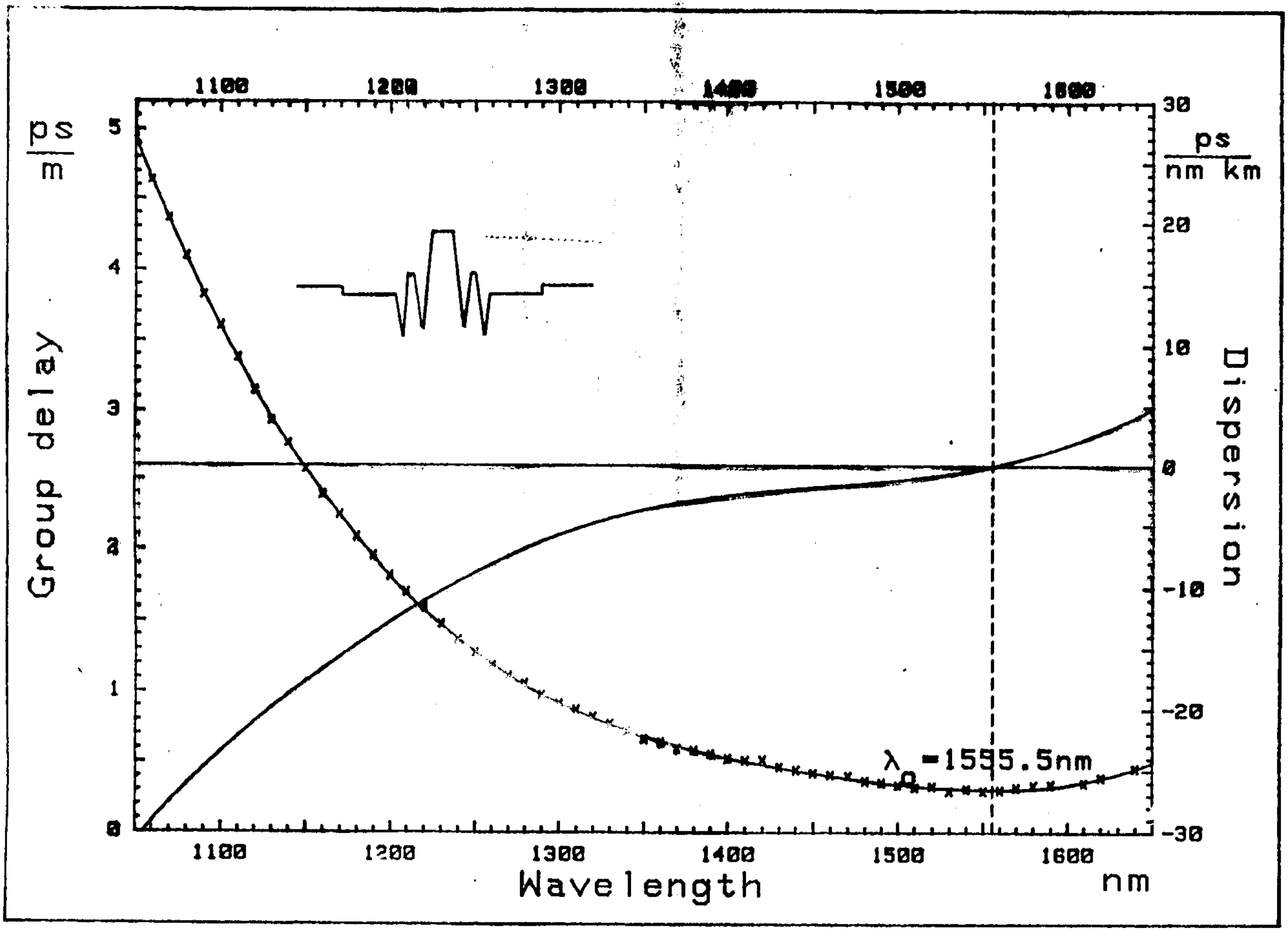
$$\tau(\lambda) = c_1\lambda^{-4} + c_2\lambda^{-2} + c_3 + c_4\lambda^{2} + c_5\lambda^{4}$$

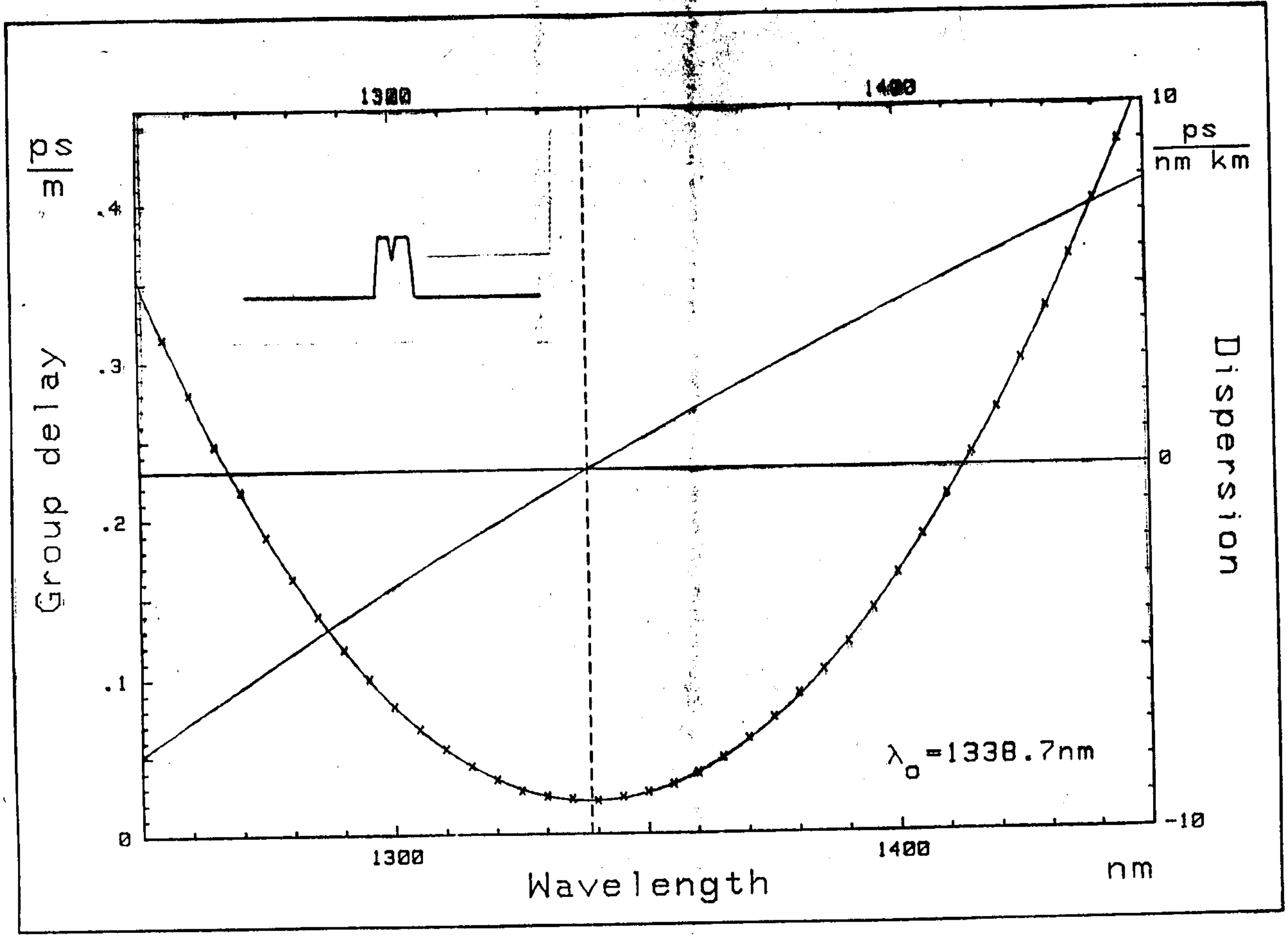
or polynomial expression

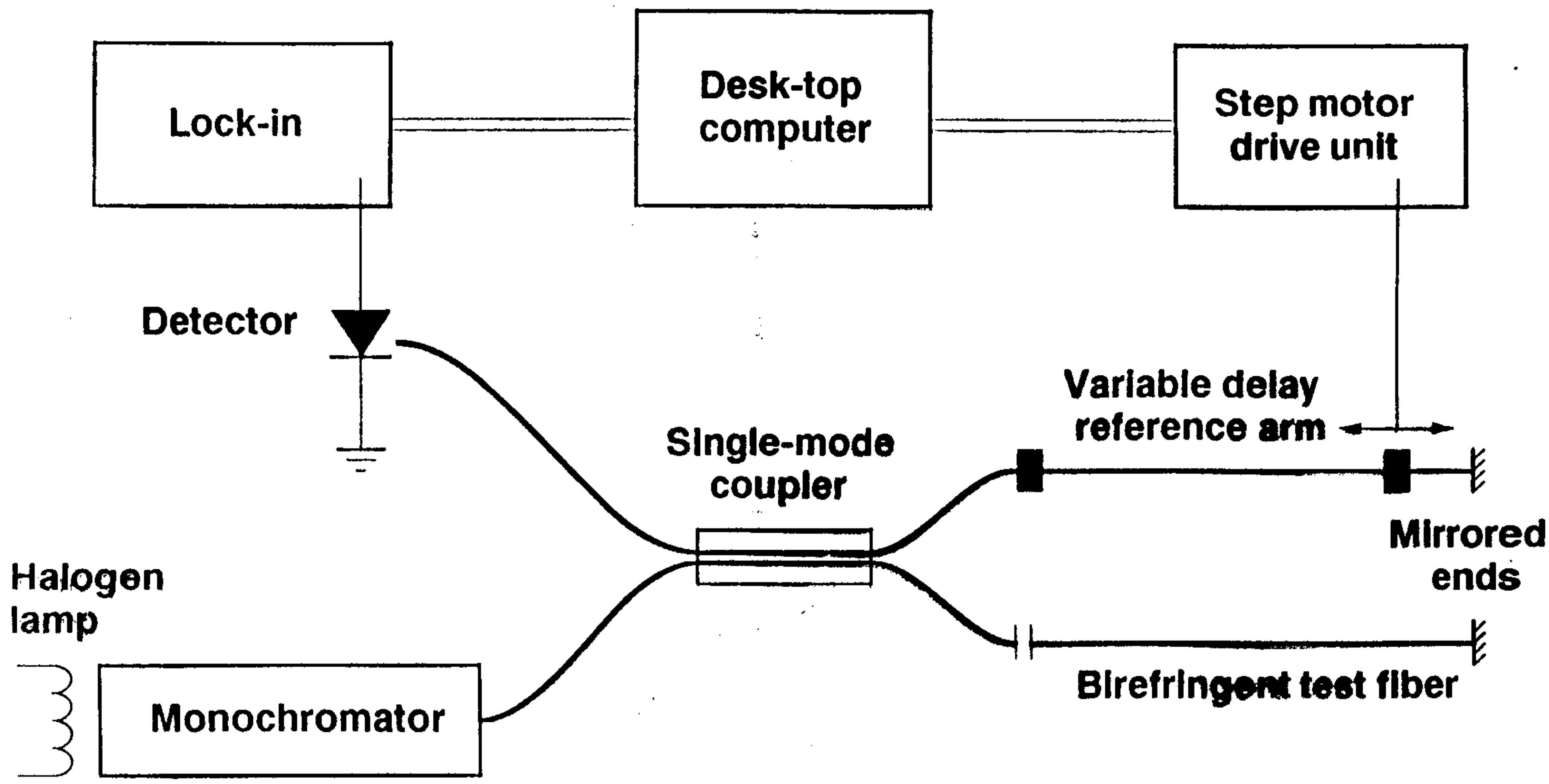


INTERFEROMETRIE

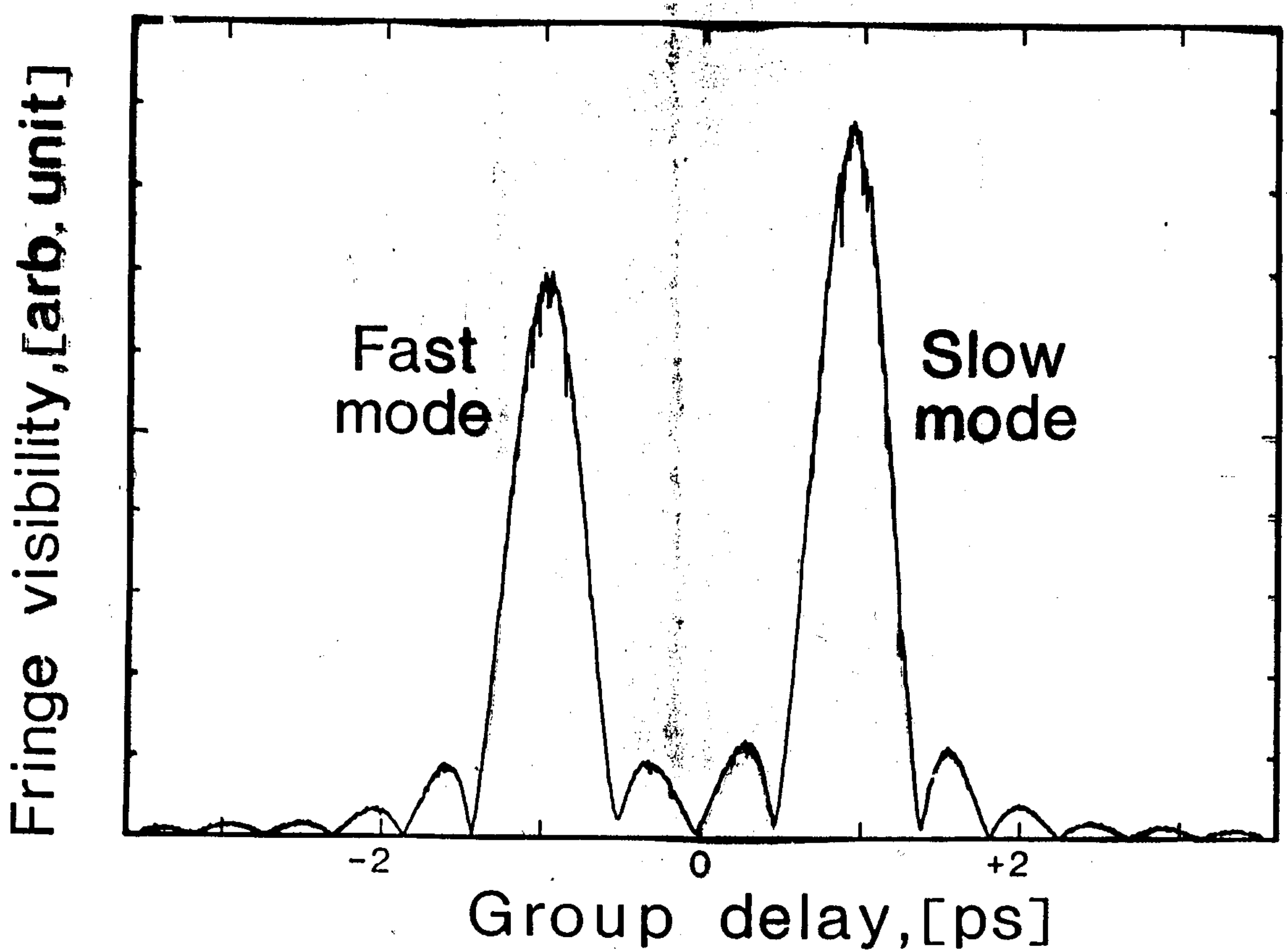



Group delay
ps/m
Dispersion
ps/(nm km)
Wavelength
nm
λ0 =1555.5nm
1100
1200
1300
1400
1500
1600
0
1
2
3
4
5
30
20
10
0
-10
-20
-30


Group delay
ps/m
.4
.3
.2
.1
0
1300
1400
Wavelength
nm
Dispersion
ps/(nm km)
10
0
-10
λ_o=1338.7nm

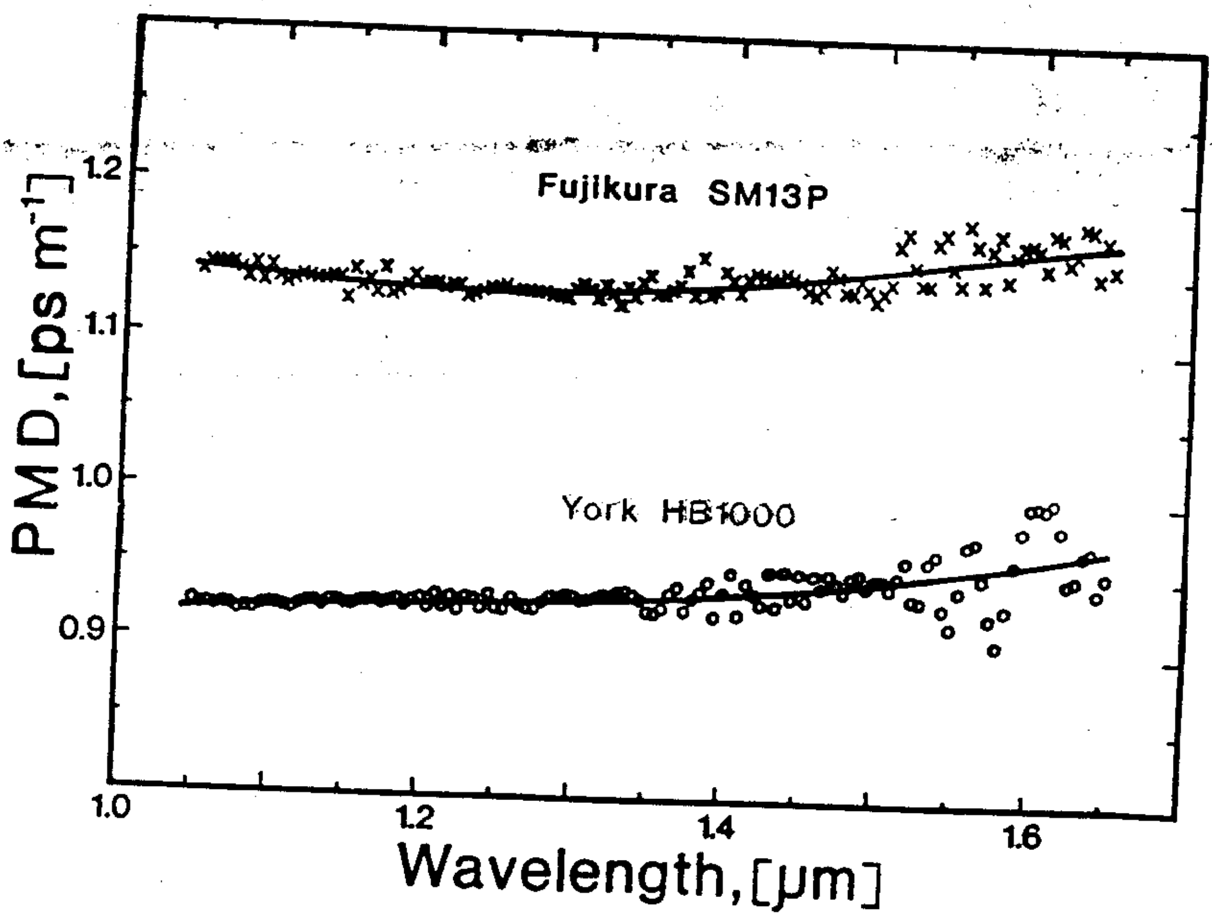


Lock-in
Desk-top computer
Step motor drive unit
Detector
Variable delay reference arm
Single-mode coupler
Mirrored ends
Halogen lamp
Monochromator
Birefringent test fiber

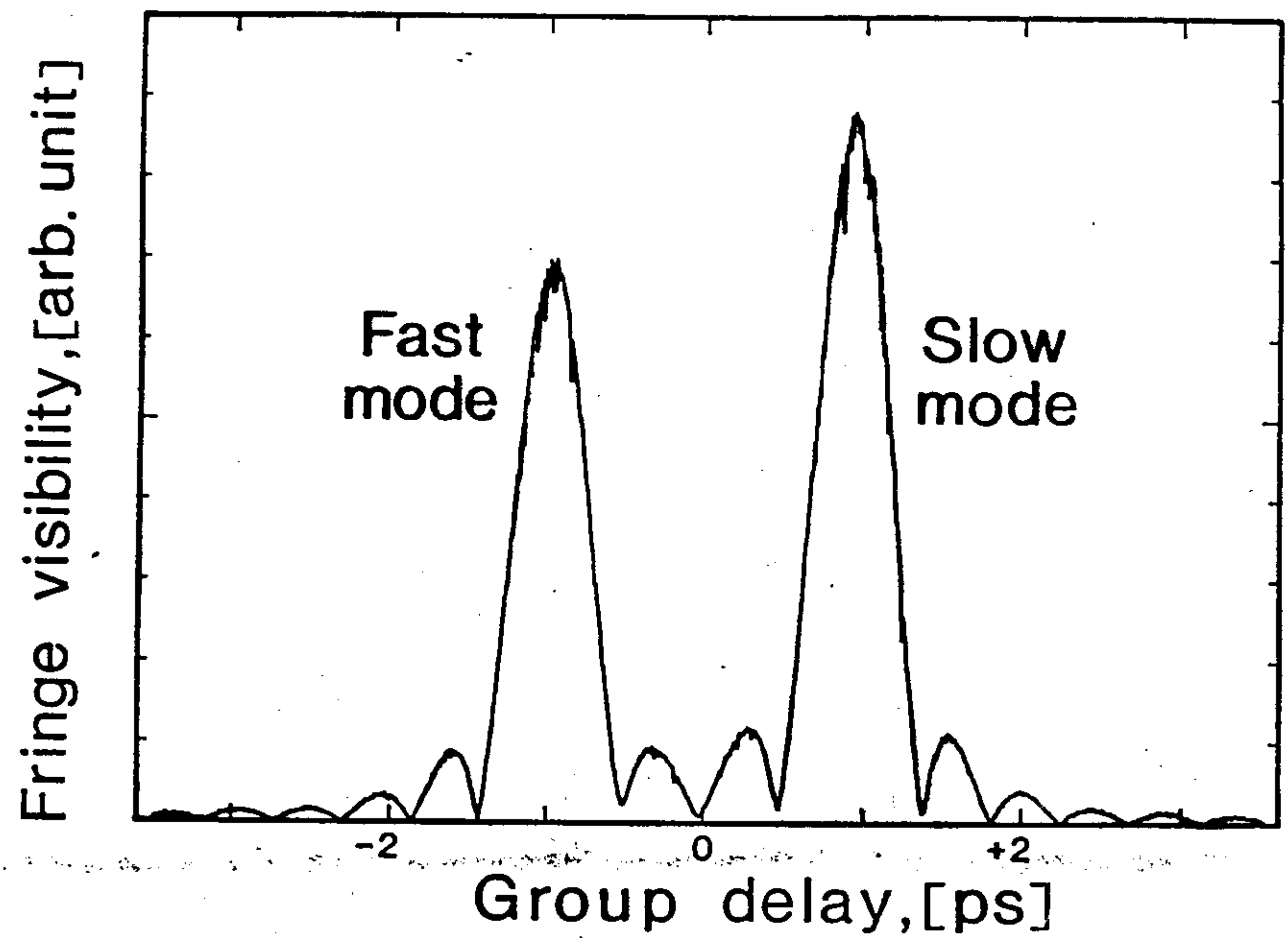

Fringe visibility,[arb. unit]
Fast
mode
Slow
mode
-2
0
+2
Group delay,[ps]

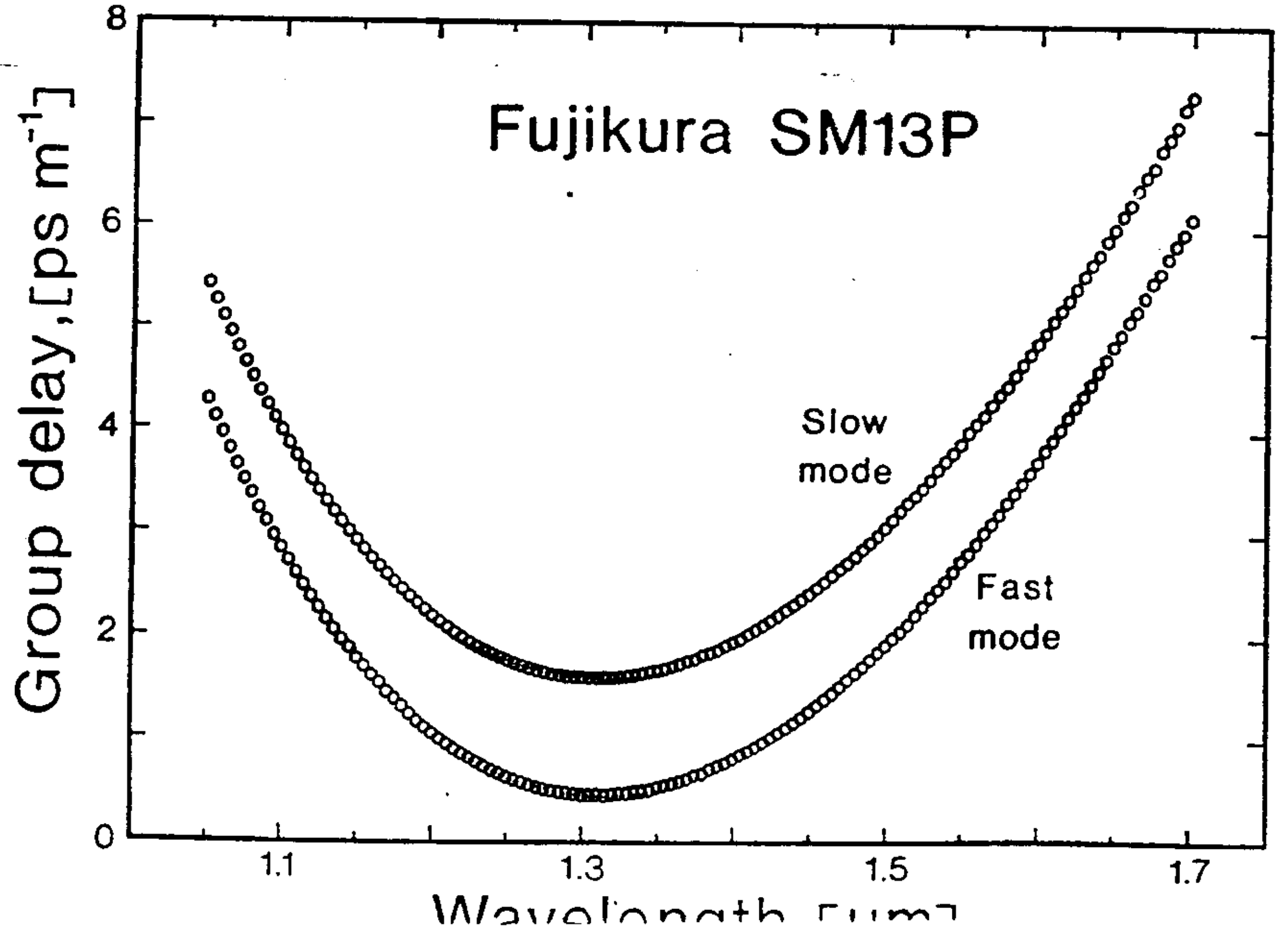
High-birefringence fibre

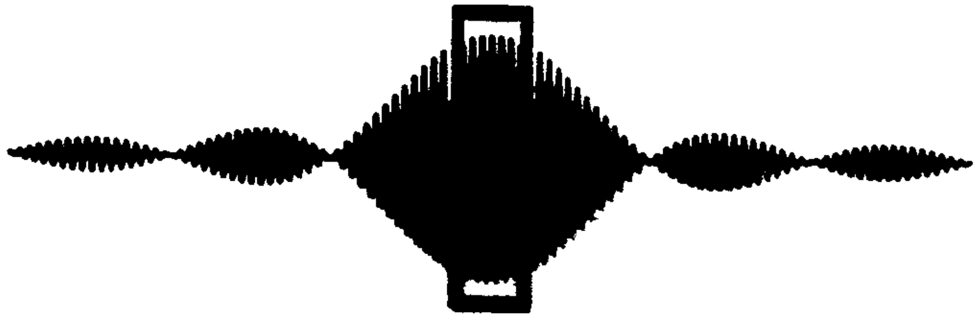
$$PMD_{min} = \frac{2\ \lambda^2}{\Delta\lambda\ L\ c}$$

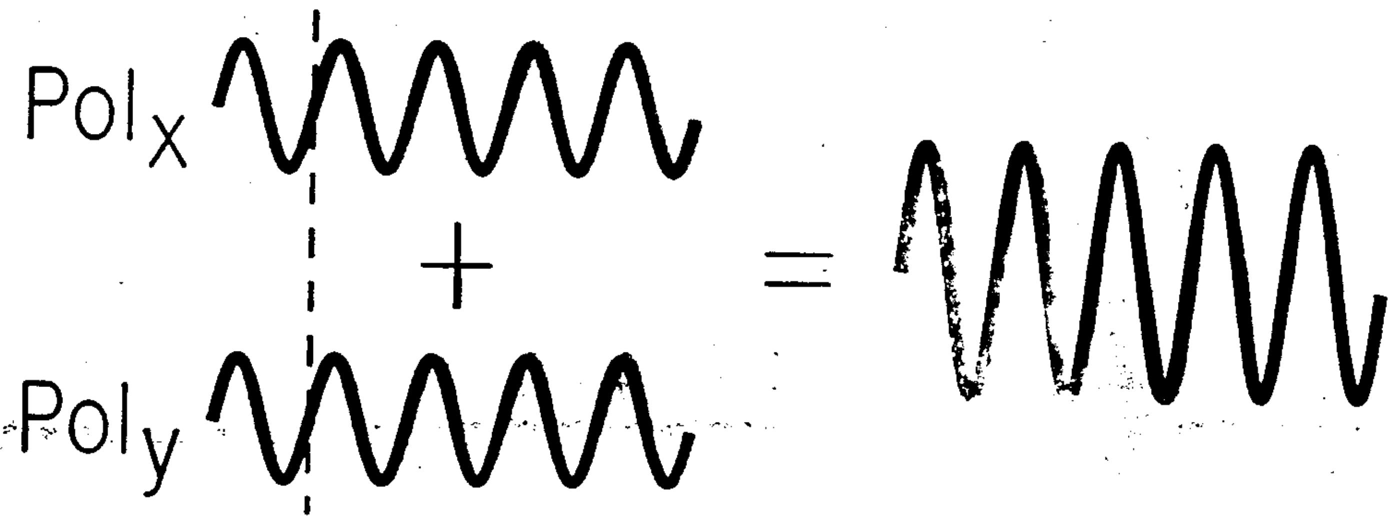


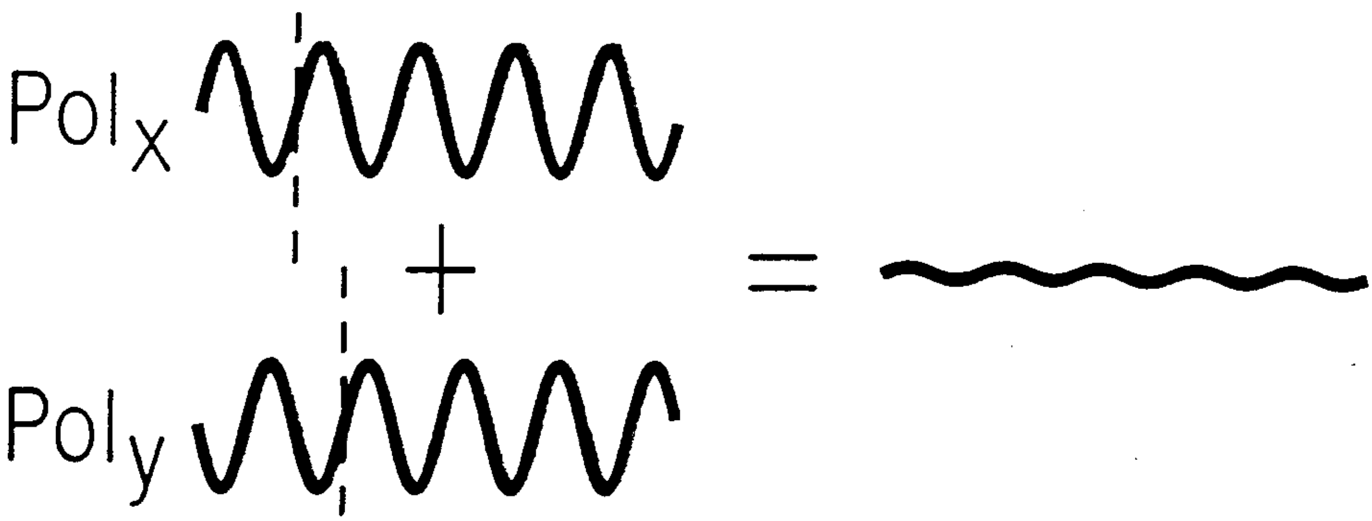
High-birefringence fibre

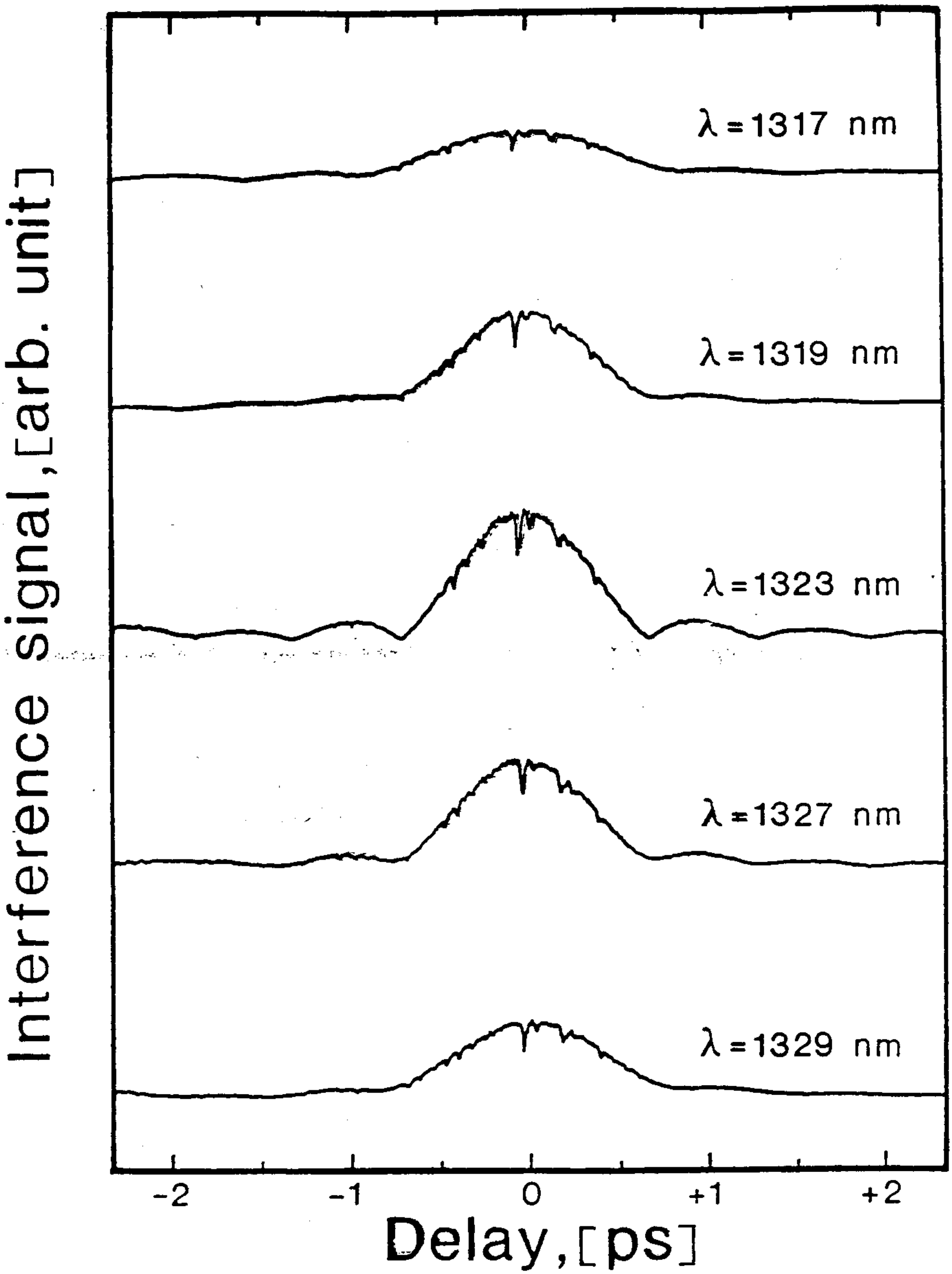






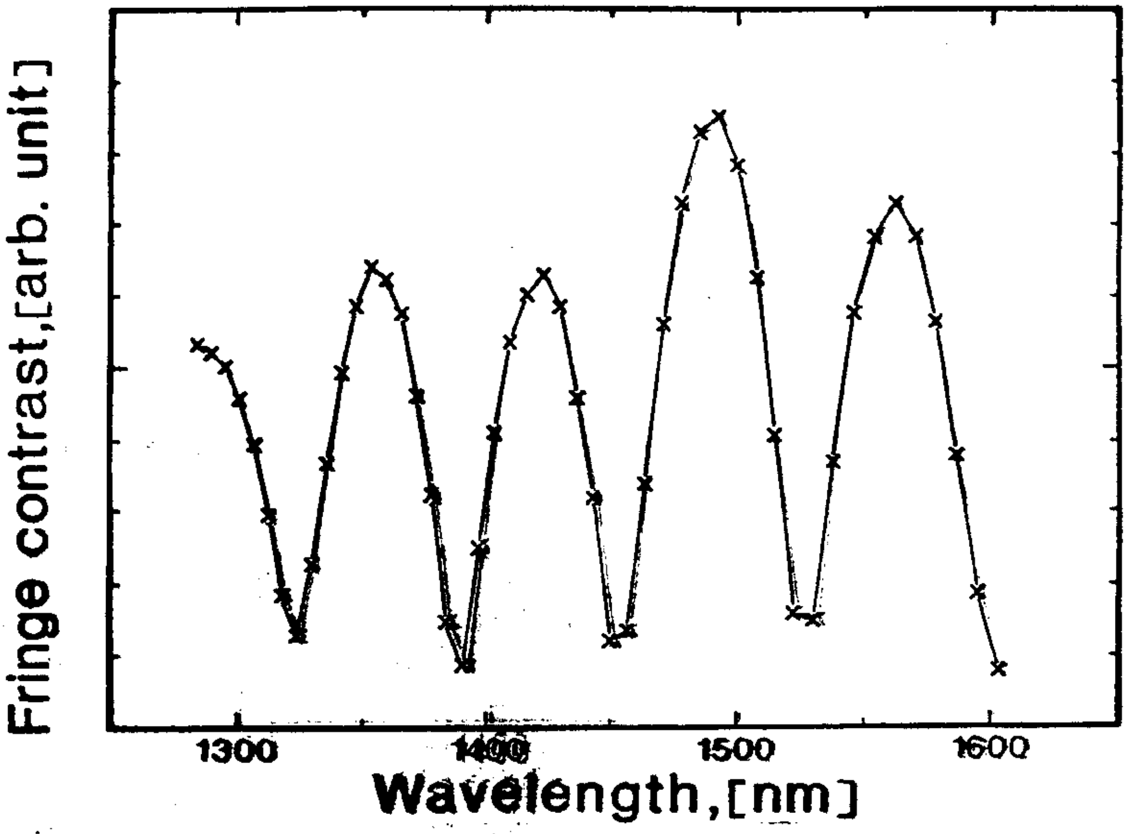

Pol X
+
Pol y
=

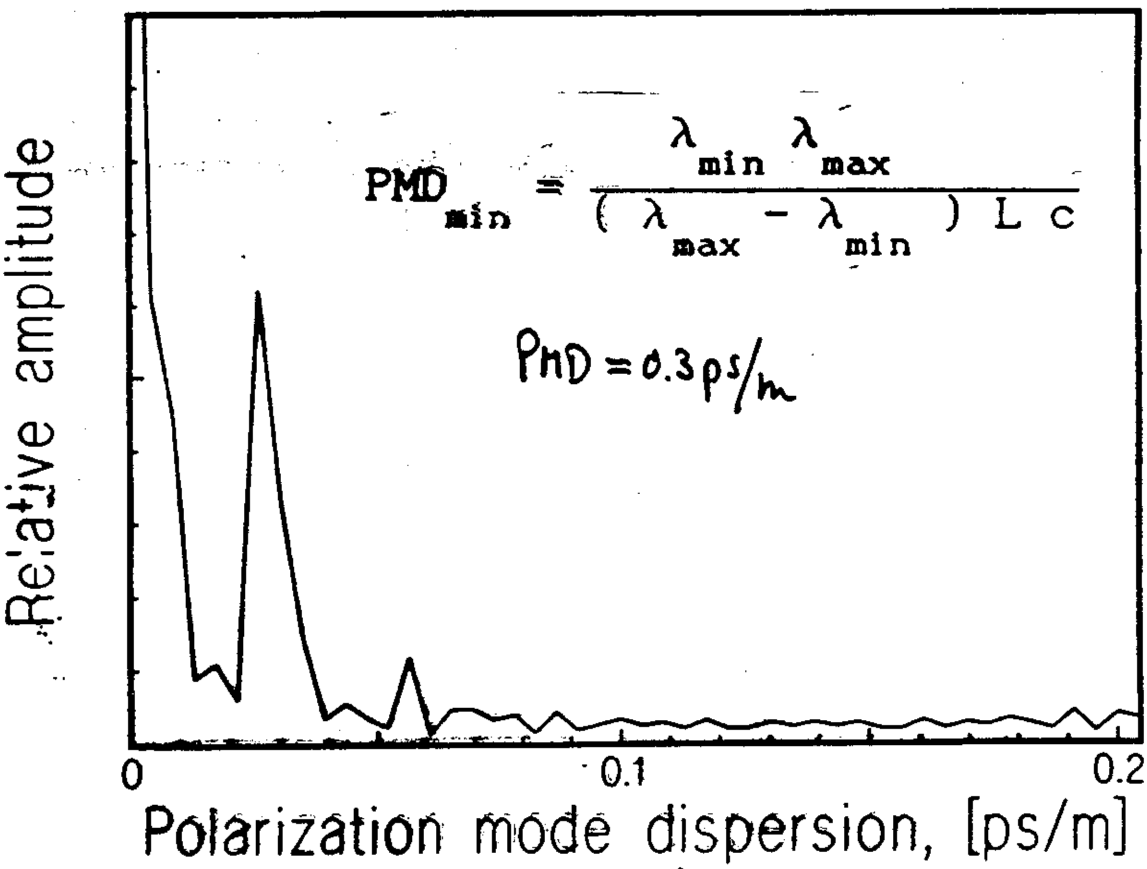

Pol X
+
Pol y
=



λ=1317 nm
λ=1319 nm
λ=1323 nm
λ=1327 nm
λ=1329 nm
Interference signal,[arb. unit]
-2
-1
0
+1
+2
Delay,[ps]

Low-birefringence fibre





Limit of the method 3 fs/m

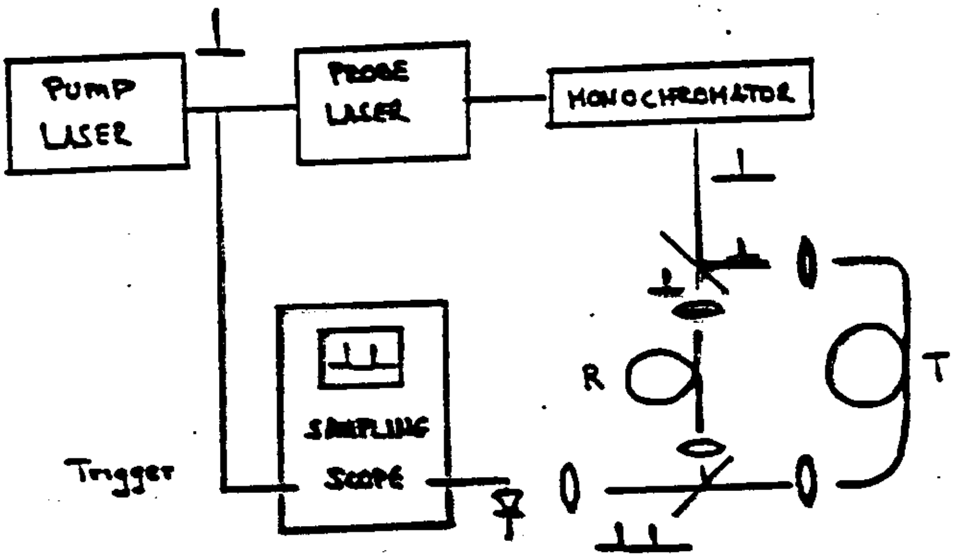


Figure 9

Resolution time typical 20ps/km

Phase-shift

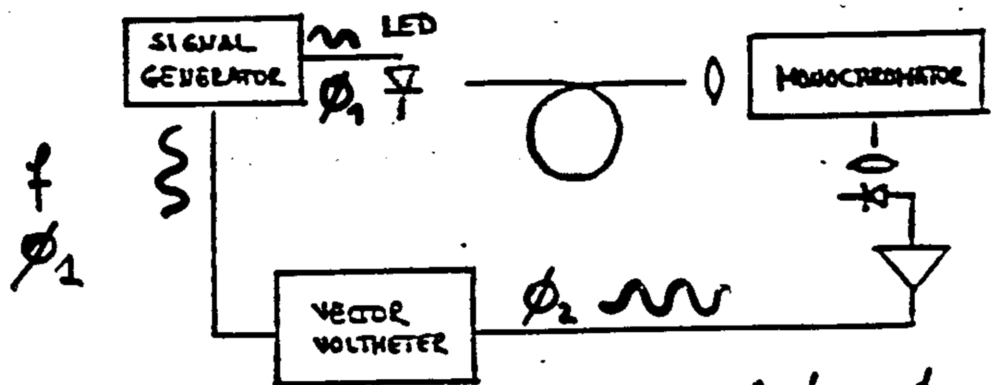


Figure 10

$$\Delta\phi = \phi_1 - \phi_2$$

$$\Delta\phi(\lambda) = \phi(\lambda_1) - \phi(\lambda_2)$$

Resolution time (10^{-1} degree over ϕ meter)

$$\Delta\tau = \frac{1}{f}\cdot\frac{1}{3600}$$

$$80\,MHz \Rightarrow \Delta\tau = 3.5\,ps$$

Problem: Optical synchronisation of the RF signal

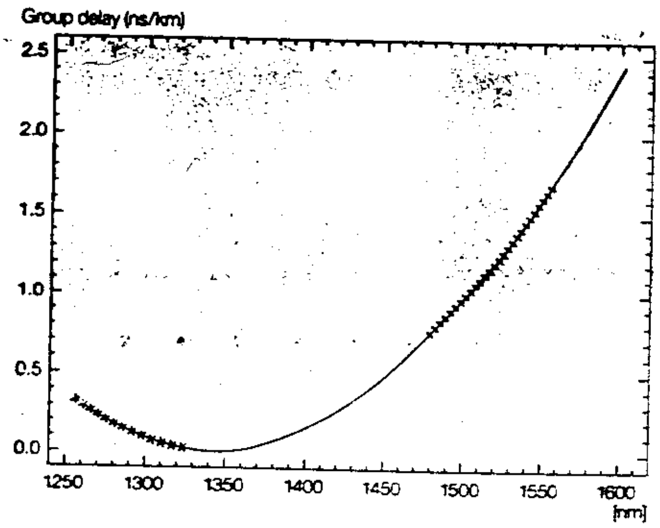
Chromatic Dispersion Meas
the optical fiber already in

All data is transmitted through the optical fiber itself;
Specially adapted for field characterization;
Transmitter completely independent of receiver;
Large wavelength scan range (two windows);
Receiver controlled by computer;
Possible to measure over long distances;
Flexible software for field operations and development.

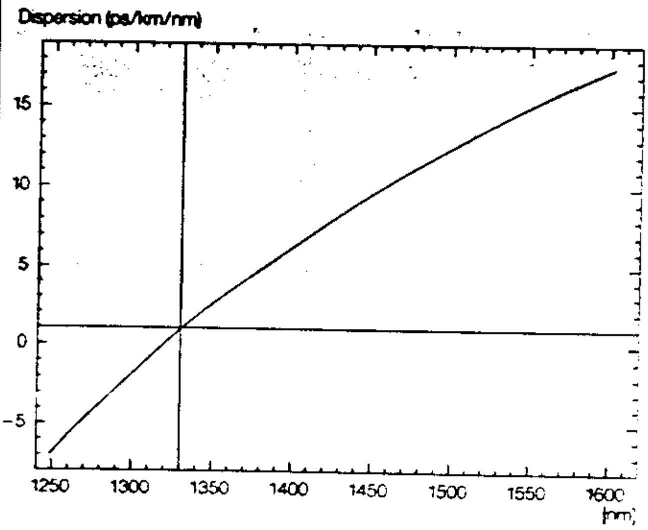
TECHNICAL DESCRIPTION

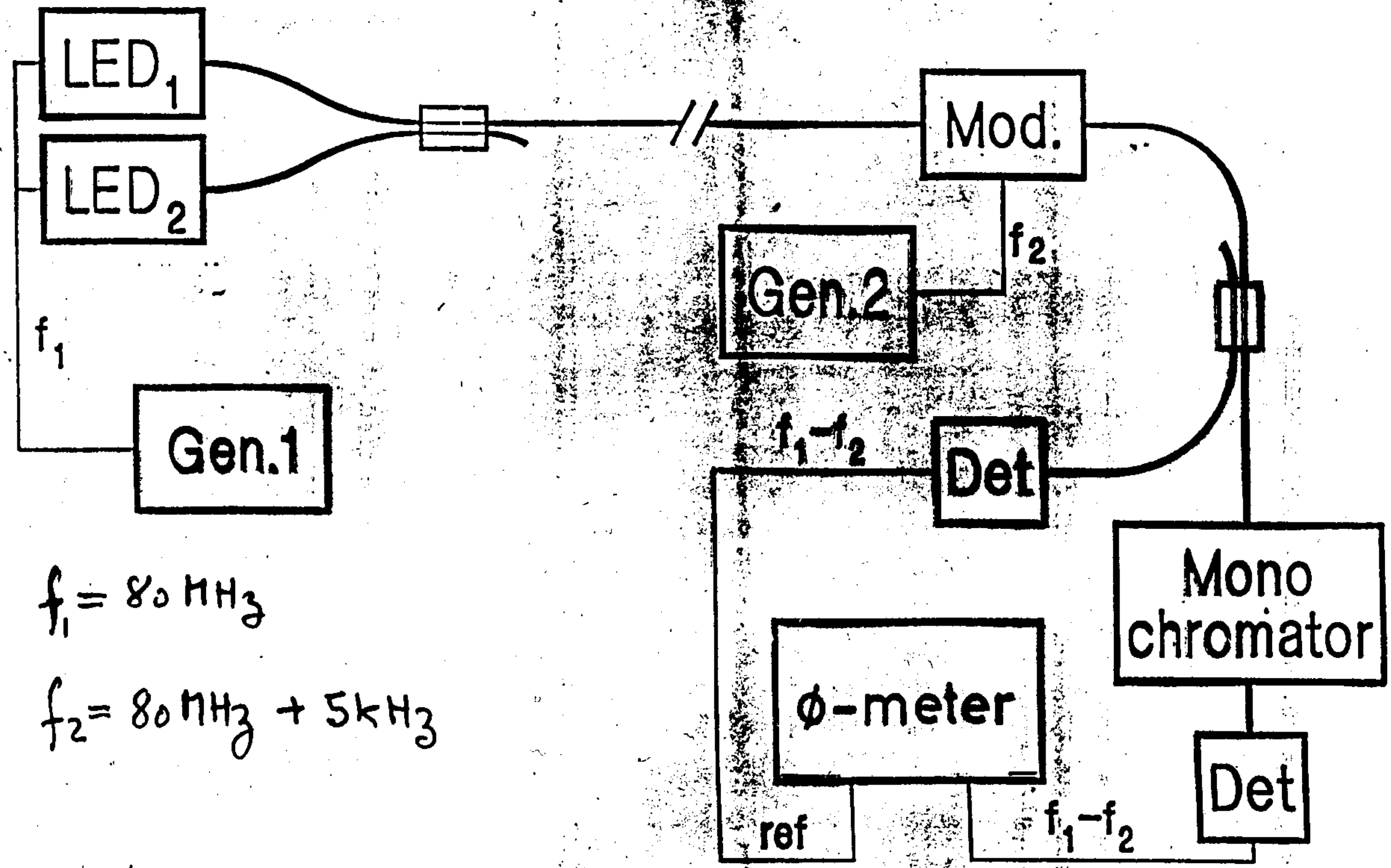
METHOD OF MEASUREMENT: Phase Shift technique. Measurement of the phase of an RF-modulated optical source (LED diodes) allows determination of the group delay after propagation through the fiber. The group delay of this RF signal after traversing the fiber is measured as a function of the optical wavelength.

A curve is fitted to these results using Sellmeier or other suitable equation (time delay curve).



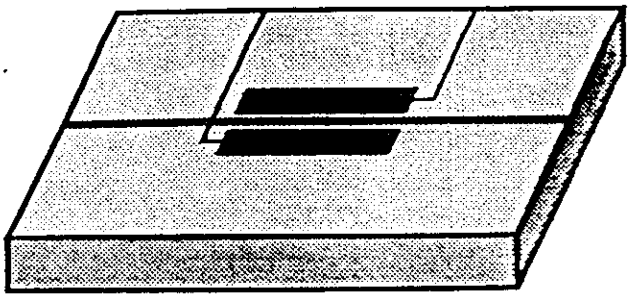
The derivative of the time delay curve constitutes the chromatic dispersion of the fiber.



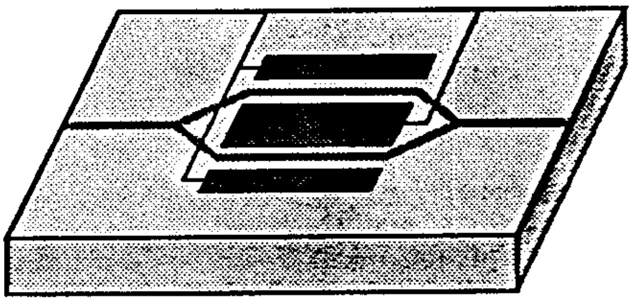


$f_1 = 80\ MHz$

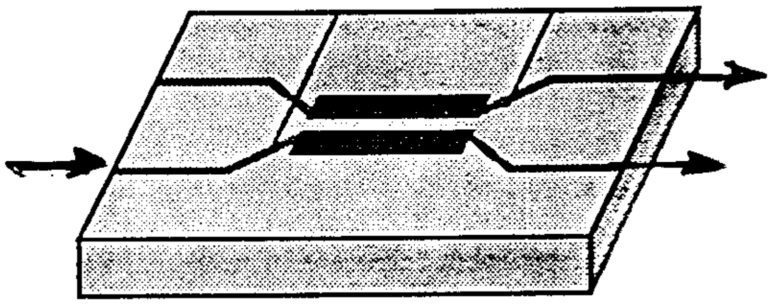
$f_2 = 80\ MHz + 5\ kHz$



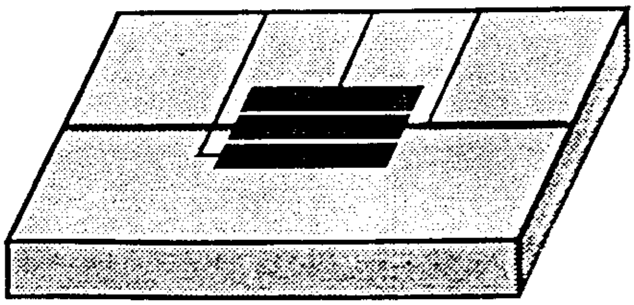
Modulateur de phase
Crystal Technology
Atténuation, f(E), Réflections,
Nonlinéarités



Modulateur d'intensité
(Mach-Zehnder)
Crystal Technology, Pilkington
Atténuation, f(E), Bande passante



Bifurcation active
(CCERA)
Thomson Sintra
Atténuation, f(E), Bande passante.

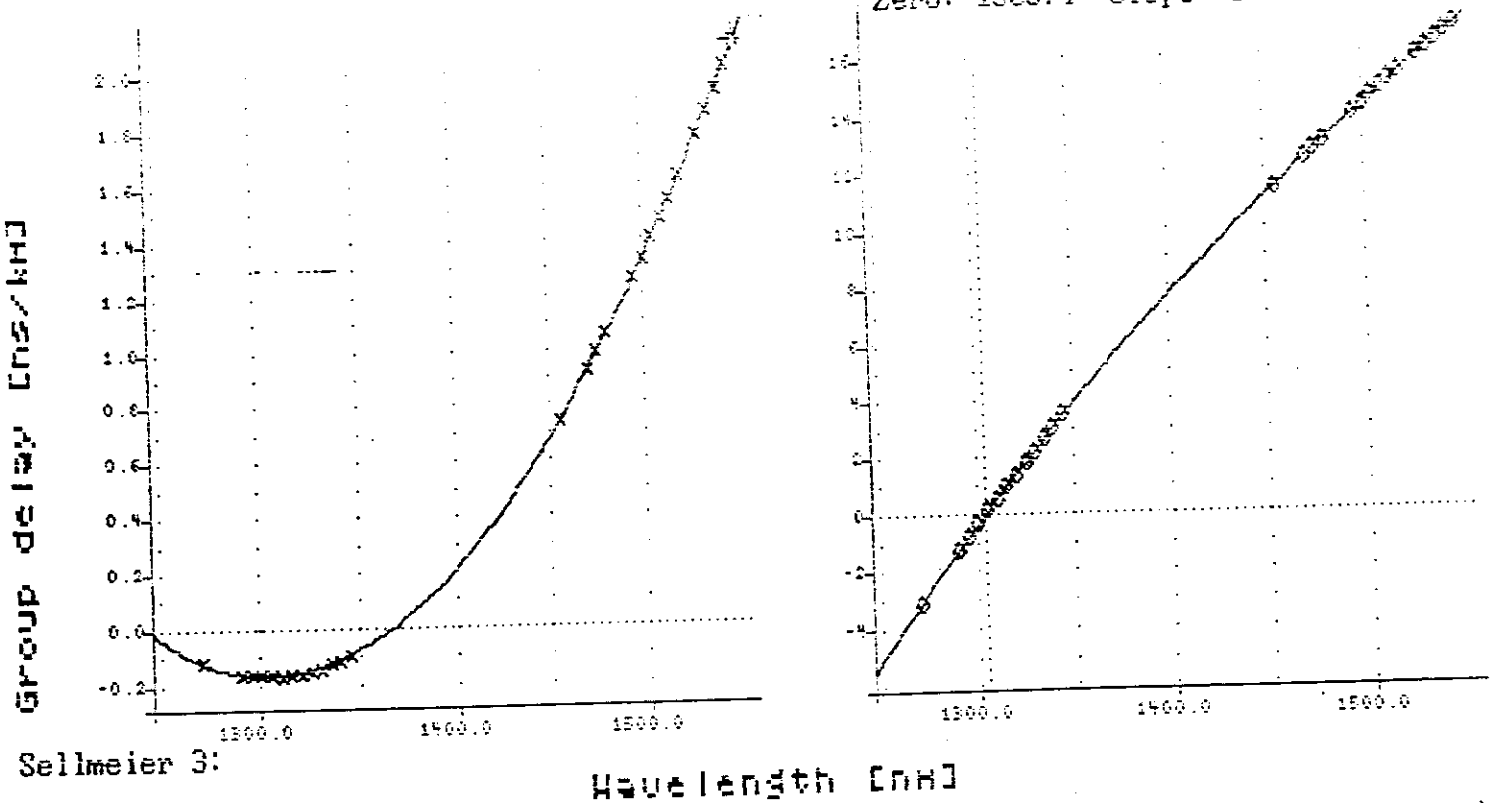


Contrôleur de polarisation
Crystal Technology
Atténuation, (f(E))

f(E): fonction de transfert électrique-optique

RESULTS:

Wavelength: 1550 nm Group delay: 2.10 ns/km
Zero: 1303.4 Slope: 0.088



Sellmeier 3:

User name : OPG Electronics SA, cm
Cable Name : Big Bobbin. Fiber Number: 1
Cable length: 4940.00 [m]
Soft avec analyse de courbe. Beaucoup de signal.

Fit type : Sellmeier 3
Coefficients:
a = 3.178E+07
b = -3.758E+01
c = 1.101E-05

Lambda zero : 1303.4 [nm] Slope: 0.088 [ps/km/nm/nm]

File name : ARCH\MES20.DCF