INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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H4.SMR/452-54

ADRIATICO CONFERENCE ON FOURIER OPTICS AND HOLOGRAPHY

6 - 9 March 1990

CD - OPTICS

Prof. J. Braat

Philips Research Labs

Eindhoven, The Netherlands

6-3-1990

CD - optics

Joseph Braat
Philips Research Labs
Eindhoven / The Netherlands

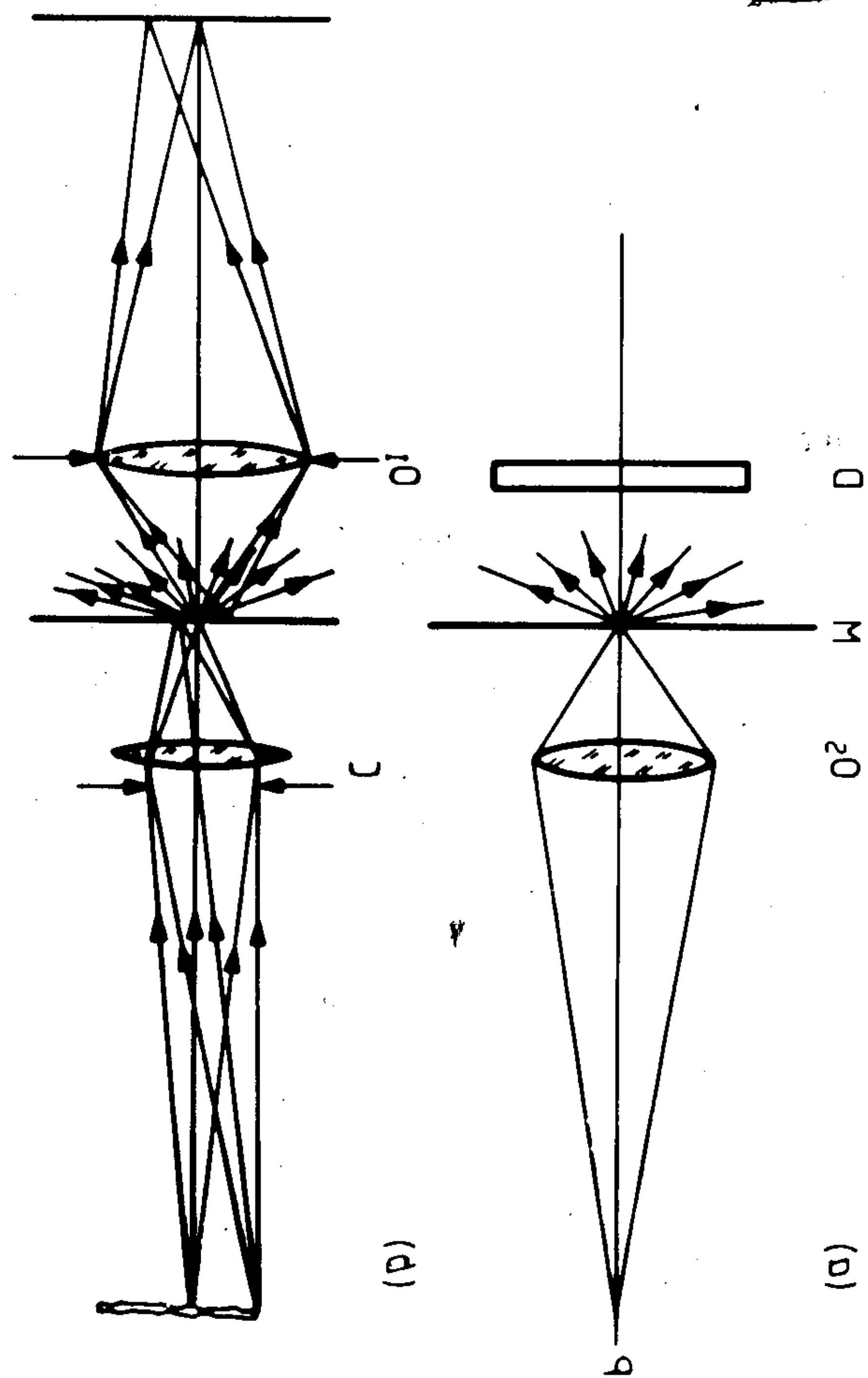
1) Diffraction model —
   - ray-optics inadequate
   - close to the diffraction-limit
   - adapted theory of image formation in a microscope

2) Optical pickup
   - lay-out
   - focussing
   - tracking

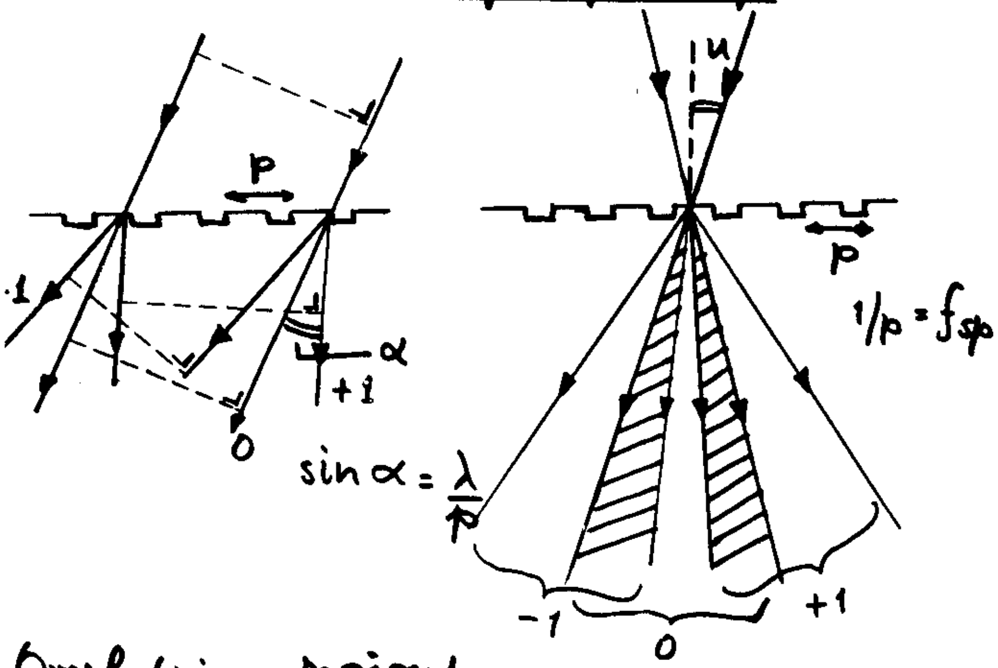
3) Signal distortion

4) CD - system

5) Recordable / erasable system



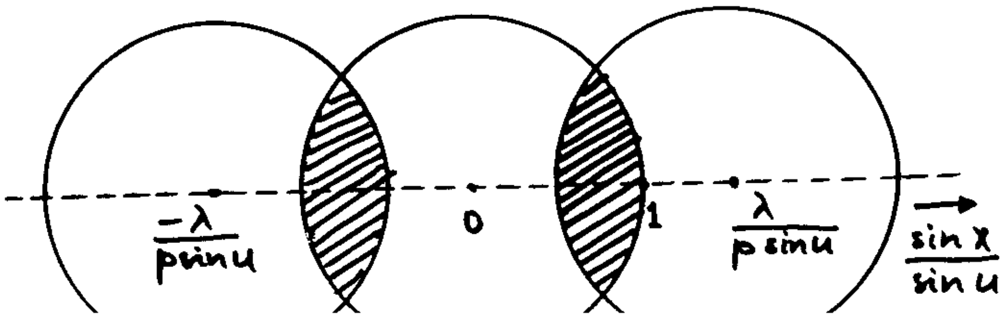
Diffraction by a grating

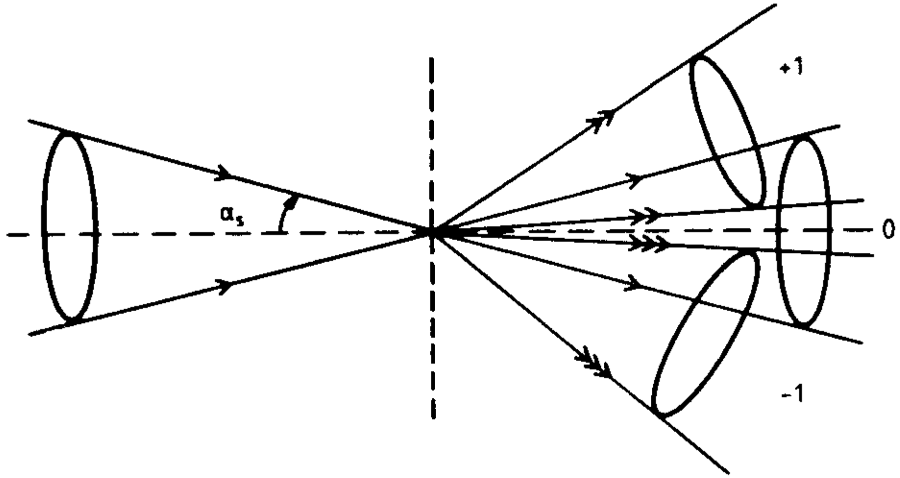


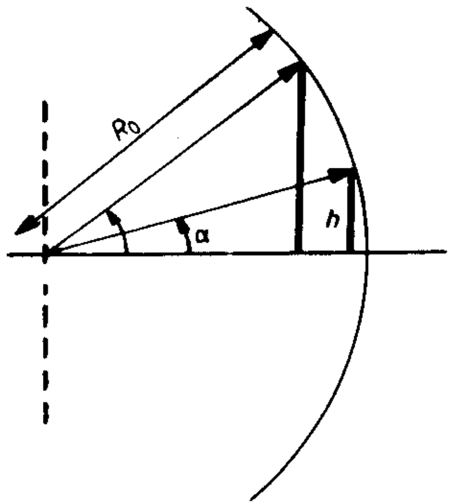
Overlapping regions

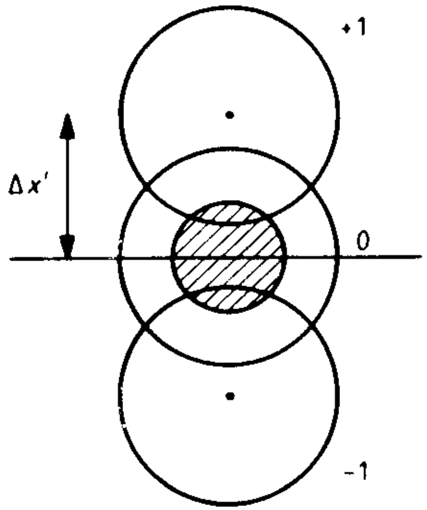
$$\sin\alpha < 2\sin u$$

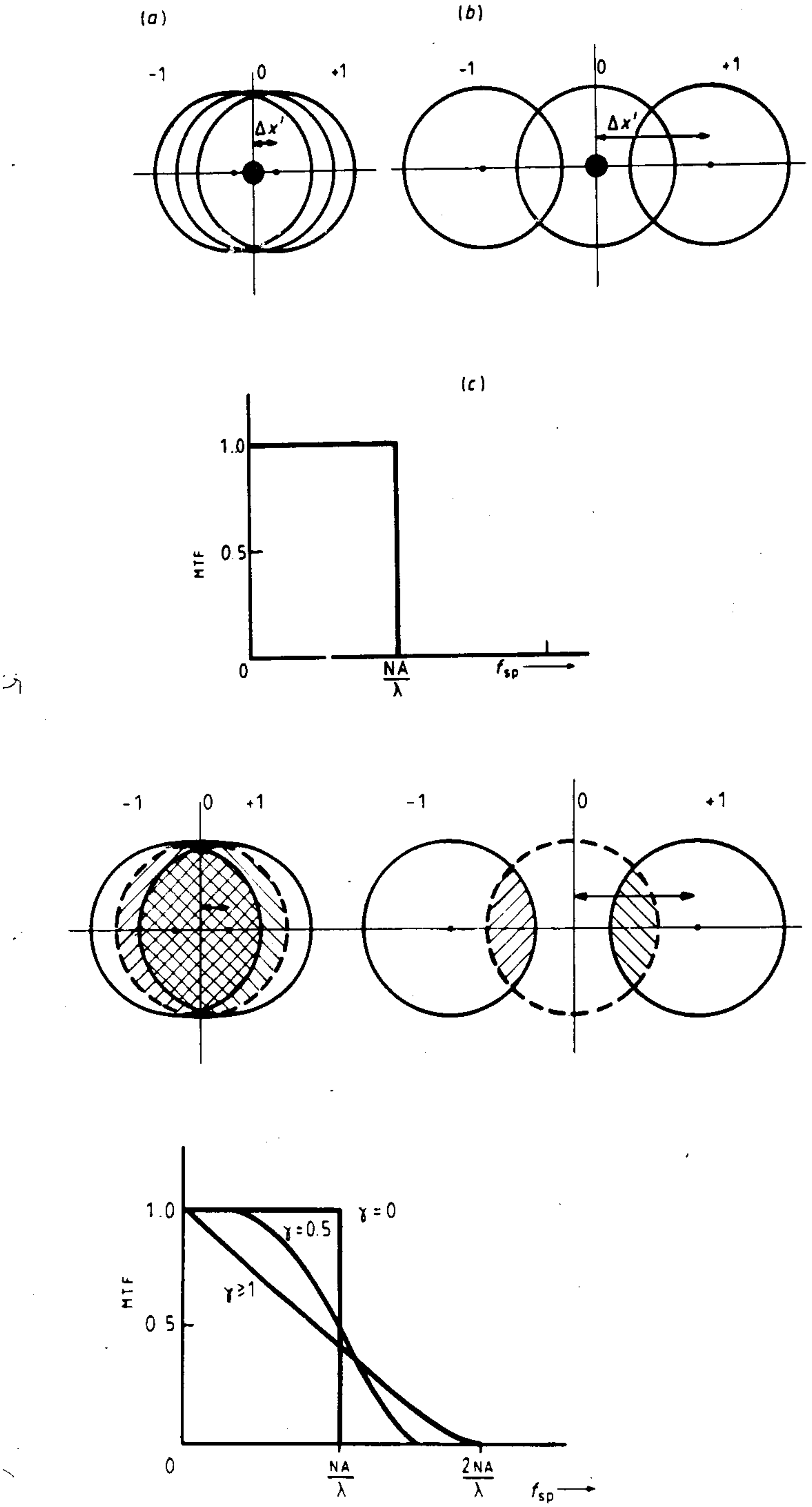
$$\frac{\lambda}{p} < 2\,NA \longrightarrow f_{sp} < \frac{2NA}{\lambda}$$





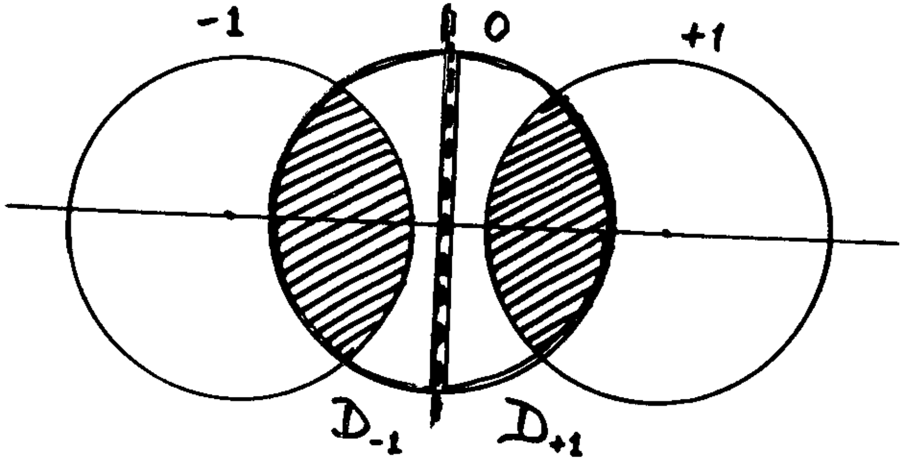






(a)
(b)
-1
0
+1
Δx'
(c)
MTF
1.0
0.5
0
NA/λ
f_sp
γ=0
γ=0.5
γ≥1
2NA/λ

Signal detection



Phase zeroth order : constant (reference)

" $+1^{ste}$ order : $\psi_0 + \omega t$ $\omega = 2\pi \frac{v}{p}$

" -1^{ste} order : $\psi_0 - \omega t$

Interference in the overlapping regions:

$$S_{D_{+1}} \propto 1 + m \cos(\psi_0 + \omega t)$$
$$S_{D_{-1}} \propto 1 + m \cos(\psi_0 - \omega t)$$

} phase difference $= 2\psi_0$

$S_{D_{+1}} + S_{D_{-1}} \propto \cos\psi_0 \cos\omega t$ (CA-detection)

$S_{D_{+1}} + S_{D_{-1}} \propto -\sin\psi_0 \sin\omega t$ (PP-detection)

ϕ small ; $\psi \leq 3\pi/4 \longrightarrow$ PP

$\phi \approx \pi$; $\psi \approx \pi \longrightarrow$ CA

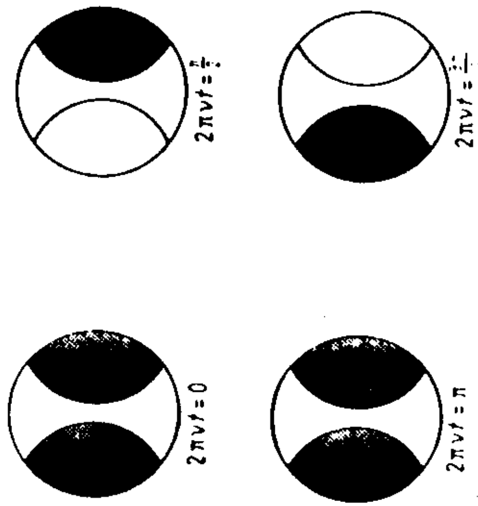
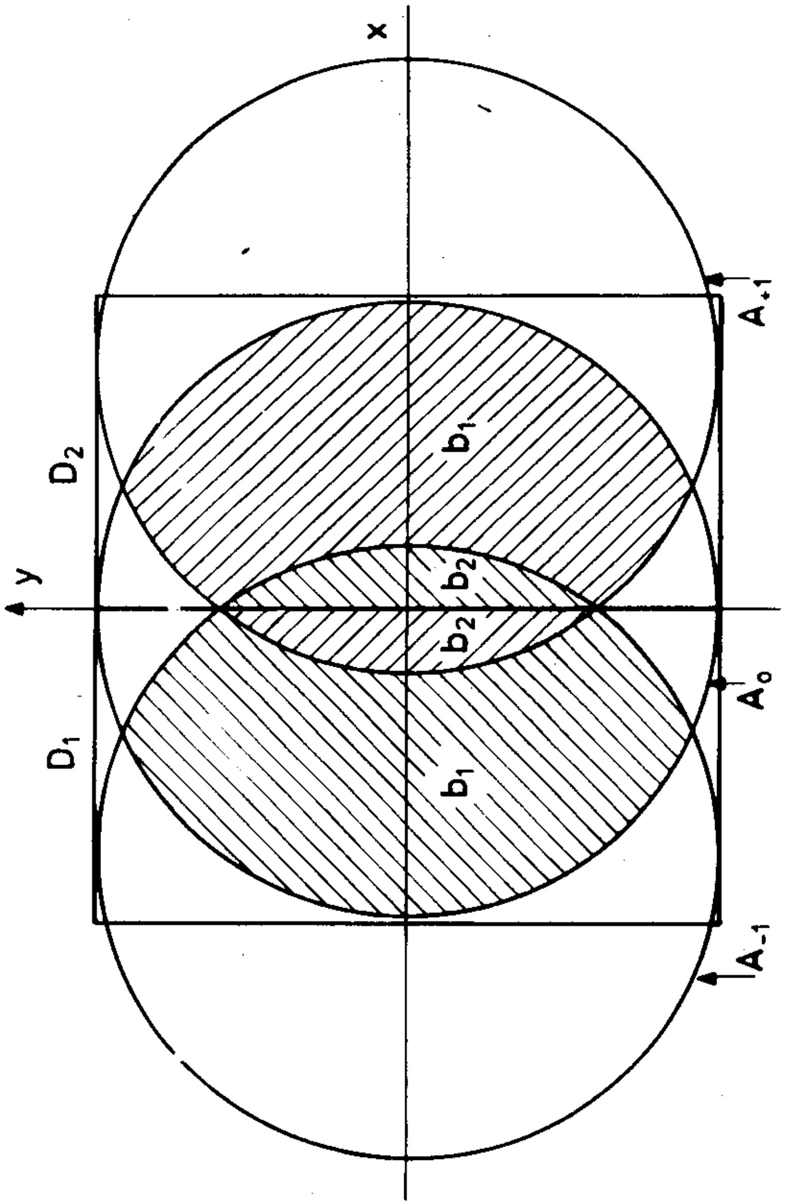
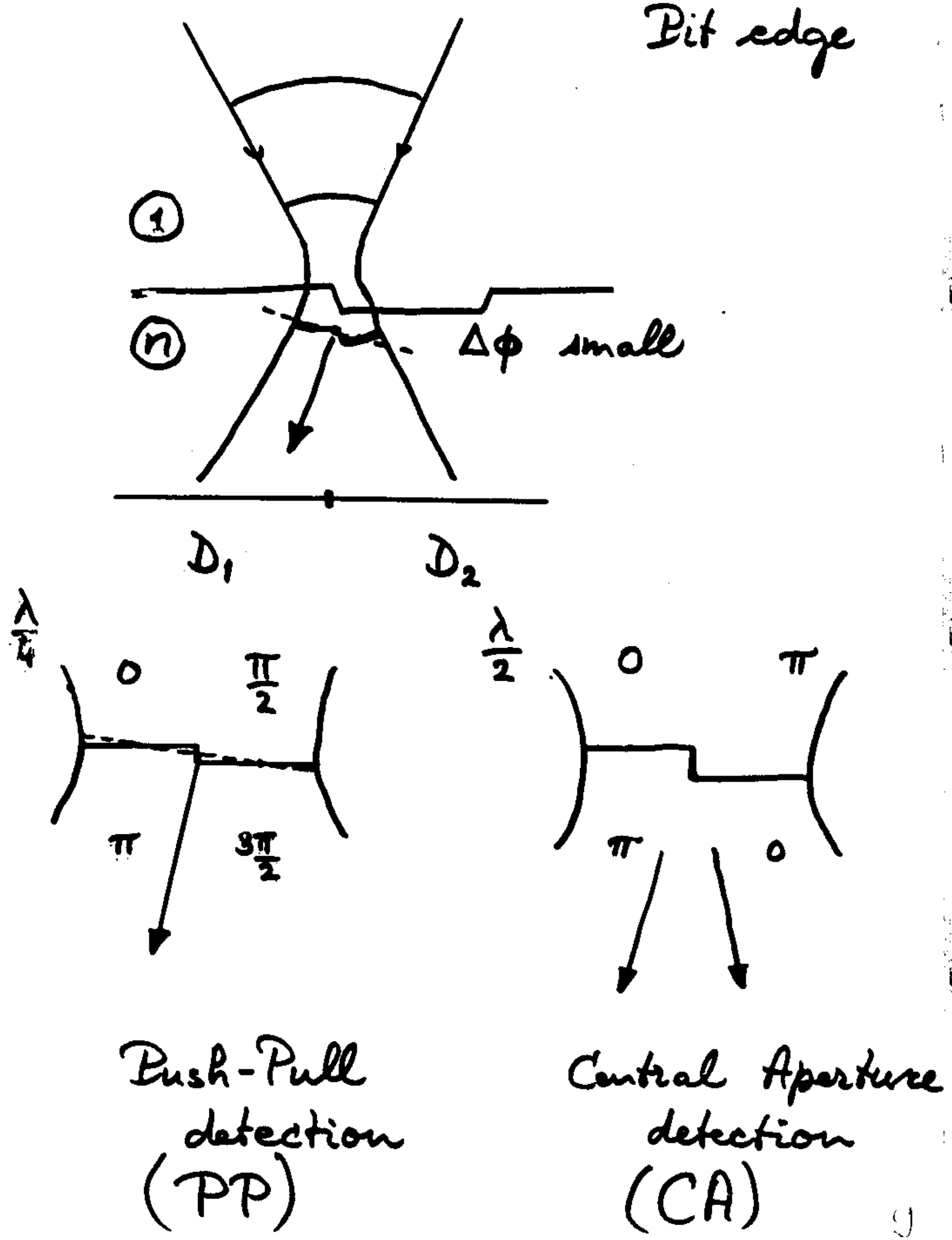


Figure 2.13 The intensity distribution over the detector area in the case of an object with a shallow phase structure on it. Only the relative changes in light intensity in the overlapping areas are indicated. Generally the central area is almost as bright as the regions of overlap so the modulation depth of the signal is small.



Diffraction



Optical Pick-up

NA 0.45 Read-out
0.52 – 0.60 Recording

λ 760 – 860 nm

$\Delta\lambda$ ± 1.5 nm

f 3 – 4.5 mm

M 0 (with collimator)
−0.25 (finite conjugates)

field Φ = 150 μm (± 1°)

Aberrations

$\frac{\lambda}{8}$ criterion (OPD_{rms} = 40 mλ)

Distorsion
Field curvature } permitted

Operating temp. 5 – 70 °C

Weight ≤ 0.5 gr (objective)

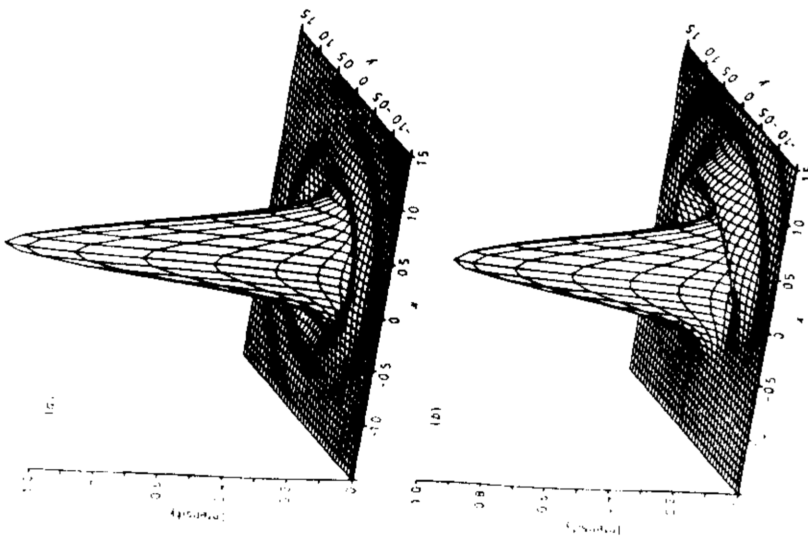
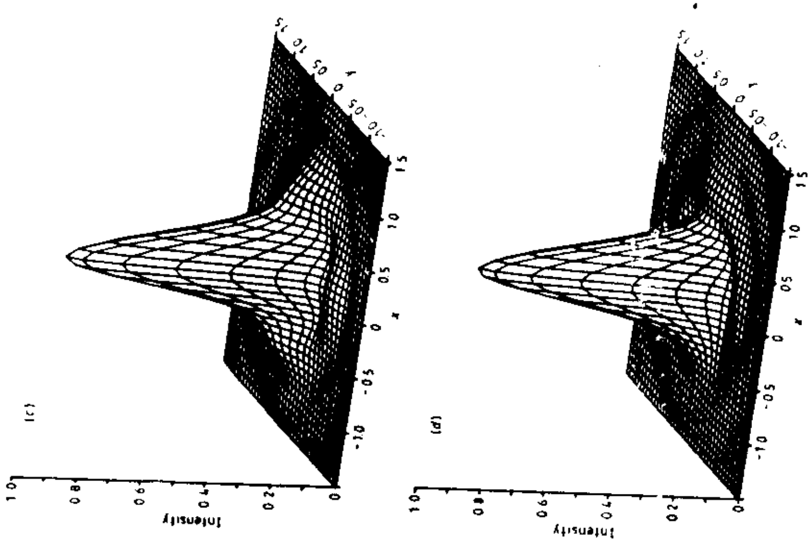
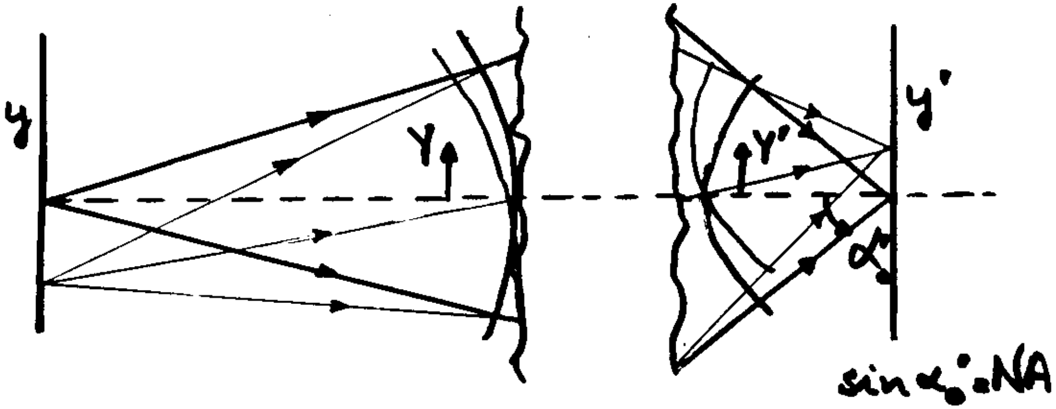


Figure 2.17 A three-dimensional plot of the intensity of the scanning spot. The x and y values are expressed in diffraction units of magnitude λ/NA. In the case of a Compact Disc player (λ = 800 nm and NA = 0.45) one diffraction unit equals 1.78 μm. (a) The focused wave is completely free of aberrations and the plotted pattern is the Airy intensity pattern. The intensity on axis is normalised to 1. (b) The incoming wave suffers from comatic aberration and is just 'diffraction limited'. The intensity on axis is 0.80. (c) The incoming wave is astigmatic and is focused on



one of its astigmatic lines. The amount of astigmatism is such that the diffraction spot could be again just 'diffraction limited'. By focusing on an astigmatic line the intensity on axis of the spot drops to 0.70. (d) The incoming wave shows several residual aberrations (see figure 2.29) and is one focal depth out of focus. The axial intensity is 0.64. Such a deterioration of the scanning spot can occur accidentally during play-back.

Aplanatic condition



$$Y = \frac{\sin\alpha}{\sin\alpha_0} \qquad Y' = \frac{\sin\alpha'}{\sin\alpha_0'}$$

$$\frac{\partial W}{\partial y'} = Y' - Y = \delta Y'$$ (y' in units λ/NA)

Sine condition (Abbe)

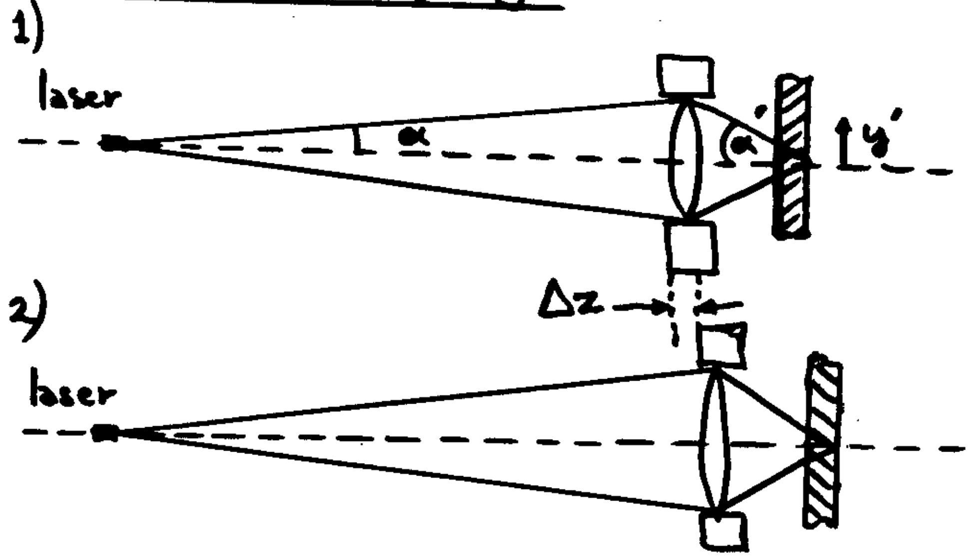
$$\frac{\partial W}{\partial y'} = \delta Y' = 0$$

or

$$\sin\alpha = \sin\alpha' \, M \qquad \left(M = \frac{y'}{y}\right)$$

Absence of linear coma!

"3D" imaging



No spherical aberration in situation 2)

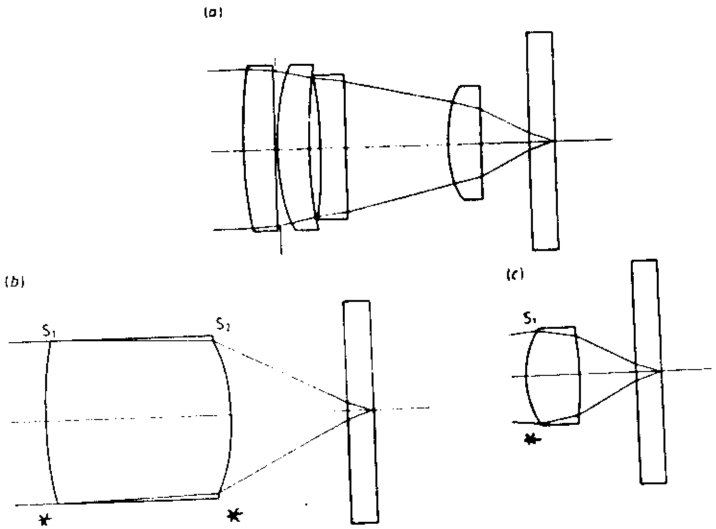
$$\sin\frac{\alpha}{2} = M \sin\frac{\alpha'}{2}$$ (Herschel condition)

OSC: $y' \, \delta Y'$

OHC: $\Delta z \left\{ \sin^2\frac{\alpha}{2} - M^2 \sin^2\frac{\alpha'}{2} \right\}$

$NA = 0.50$ $\quad y' = 75\,\mu m$ $\quad$ OPD = 25 mλ (coma)

$\begin{cases} \Delta z = 500\,\mu m \\ \Delta z' = 20\,\mu m \end{cases}$ $\quad$ OPD = 15 mλ (spherical)



* aspherical

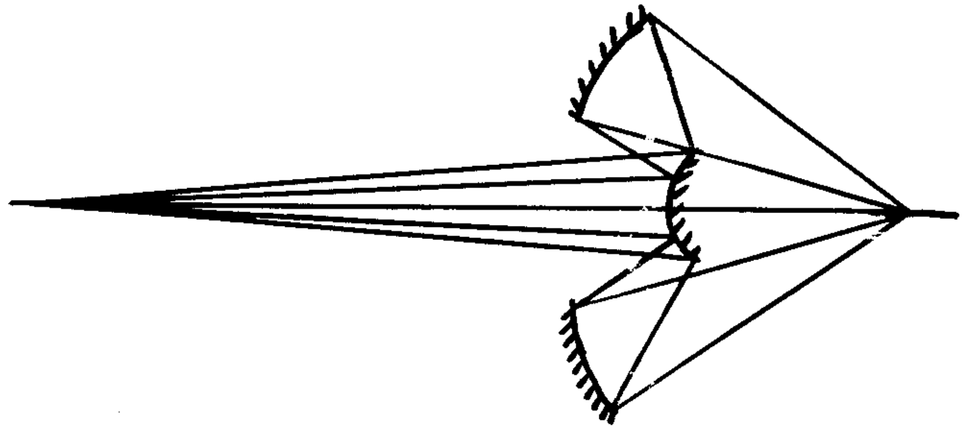
a) colour corrected
large, flat field

b) large field $\Delta\lambda \approx \pm 2.5$ nm

c) small field

Aspherical surfaces

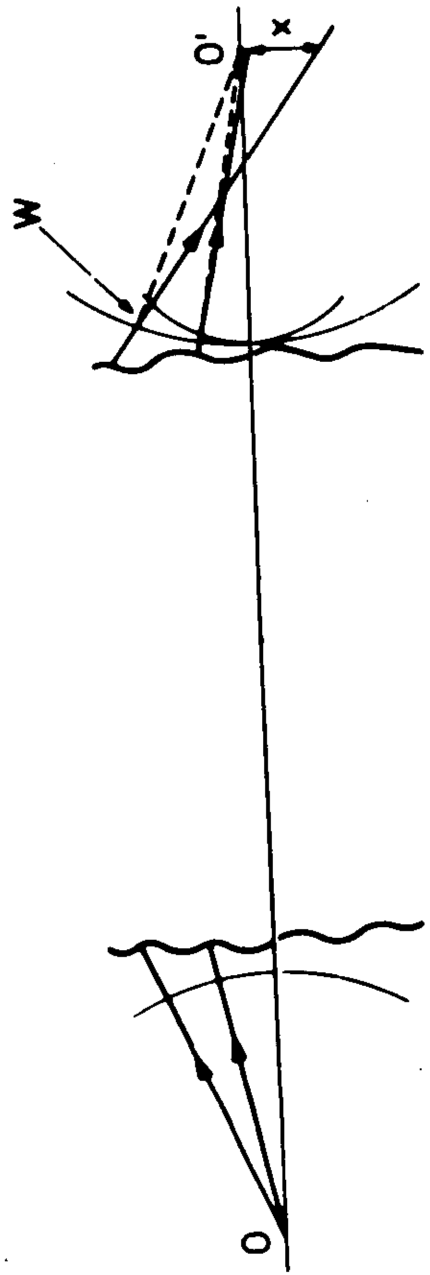
1) K. Schwarzschild (1905)
M. Linnemann (1906)



2) K. Straubel
L. Martin, C.R. Burch

3) E. Wolf diff. eq. 1948

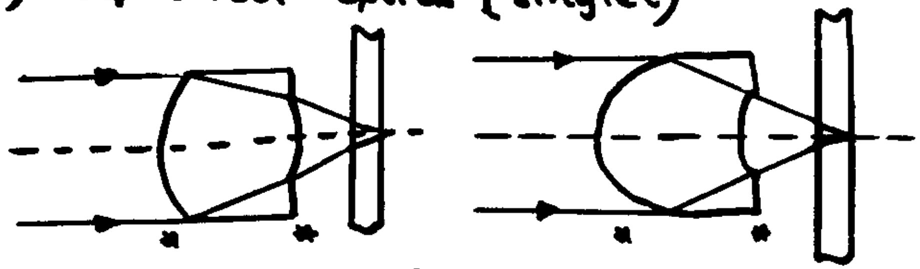
4) Realization from 1975 on



Options for scanning objective

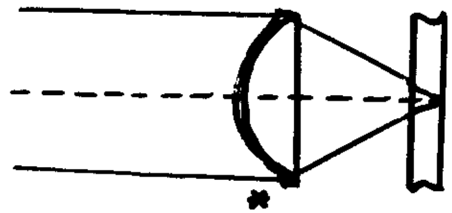
a) spherical optics
3–4 elements

b) aspherical optics (singlet)



* aspherical surface

c) replicated objective



n = 1.70 to 1.80

d) molded plastic objective

e) HOE

f) hybrid holographic / spherical

g) gradient index — axial
radial

rod lens
spherical / flat

Substrate-induced aberrations

Seidelsums of a plane-parallel plate

$$W_{sf.\,ab} = \frac{(n^2-1)}{8n^3}\, d\, \frac{(NA)^4}{\lambda}$$

$$W_{coma} = \frac{n^2-1}{2n^3}\, d\,\Theta\, \frac{(NA)^3}{\lambda} \qquad (\Theta \ll 1)\ \text{tilt}$$

$$W_{ast} = \frac{n^2-1}{2n^3}\, d\,\Theta^2\, \frac{(NA)^2}{\lambda}$$

Tolerances ($n = 1.57$, $d = 1200\,\mu m$)

$\Delta d = 100\,\mu m$ — OPD = 25 mλ (sf. ab)

$\Theta = 0{,}5^\circ$ — OPD = 50 mλ (coma)

($\lambda = 0.8\,\mu m$)

Equal Resolution (λ/NA)

$W_{sf\,ab} \propto \lambda^3$

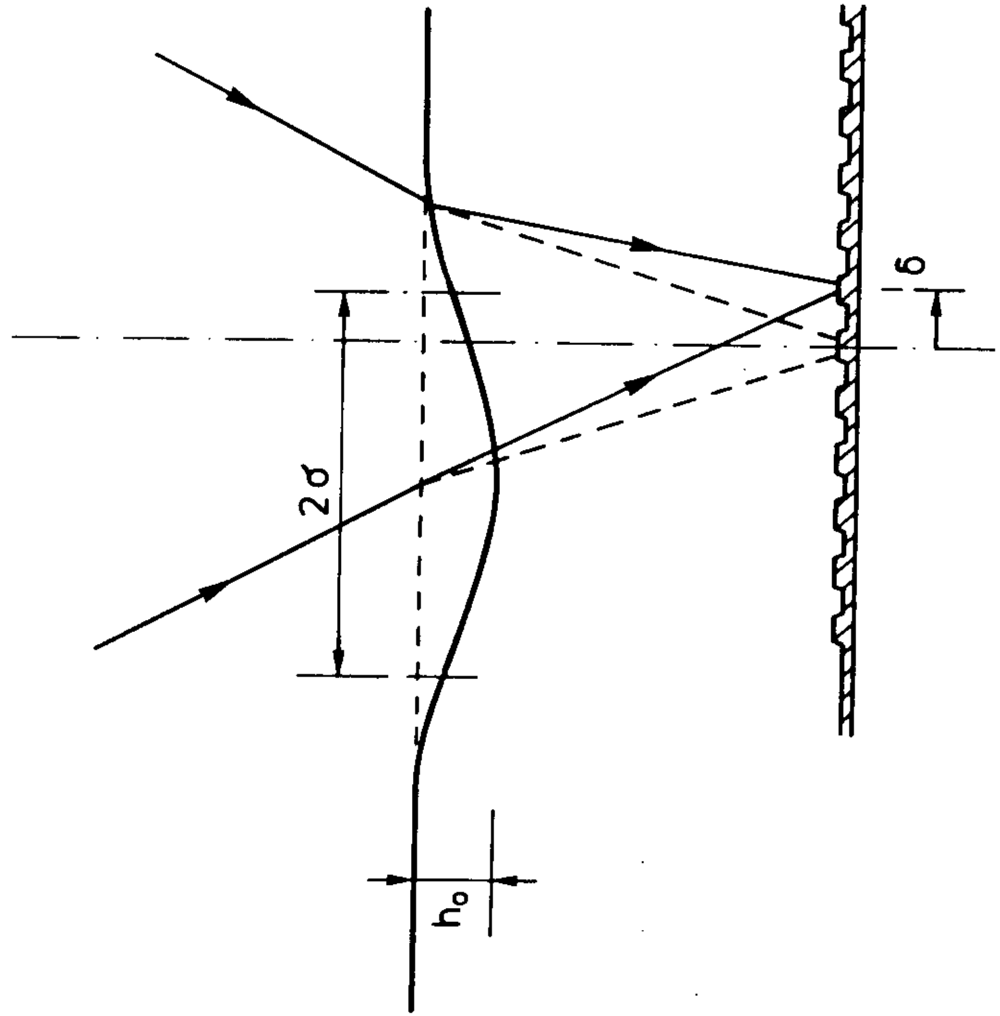
$W_{coma} \propto \lambda^2$

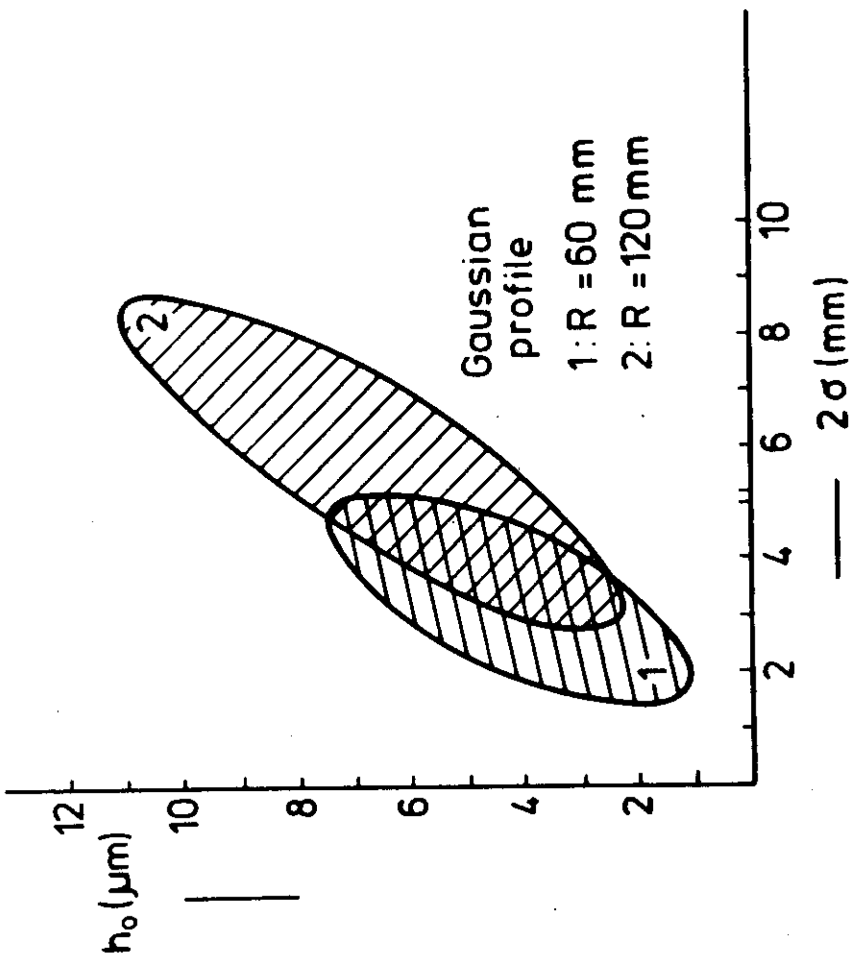
W_{ast} defocus $\propto \lambda$

High Density ($NA = 0.65$, $\lambda = 0.4\,\mu m$)

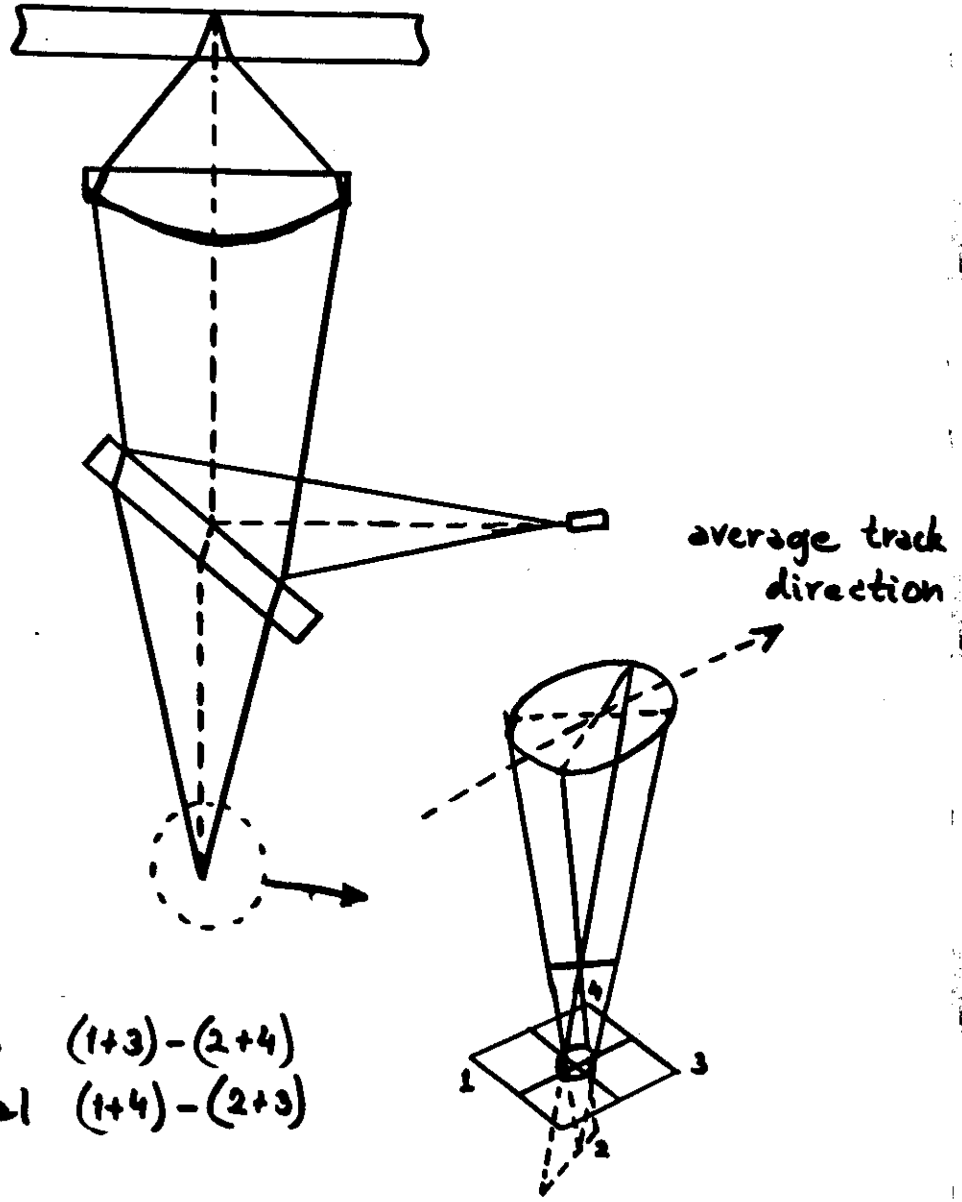
$\Delta d = 12\,\mu m$ (sf. ab)

$\Theta = 0.5^\circ$ at $d = 200\,\mu m$





Light path CD (astigmatic)



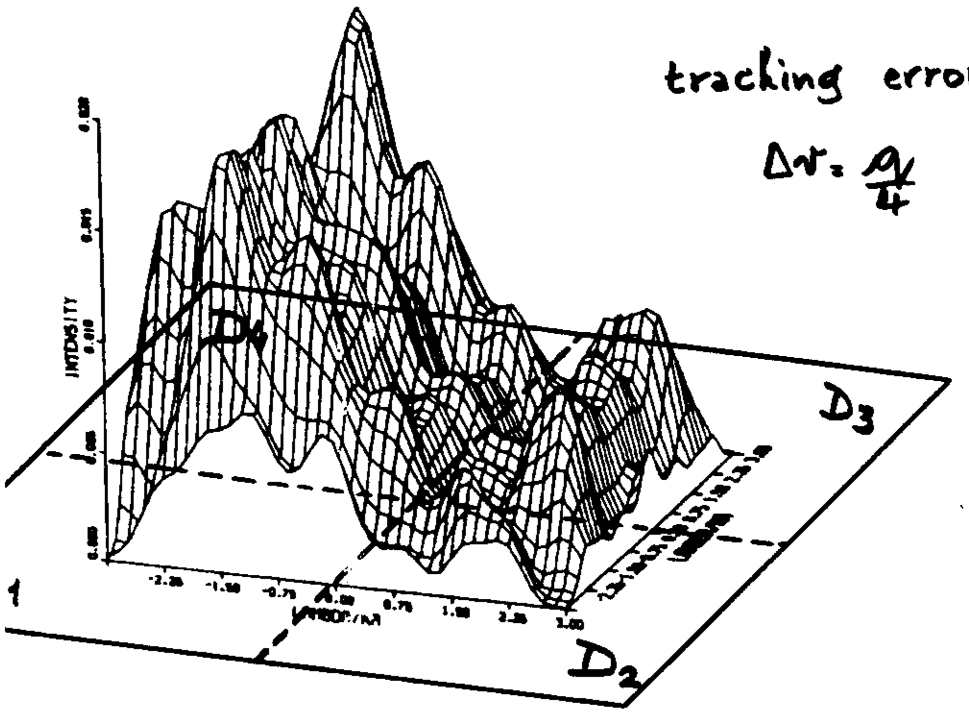
focus (1+3) - (2+4)

radial (1+4) - (2+3)

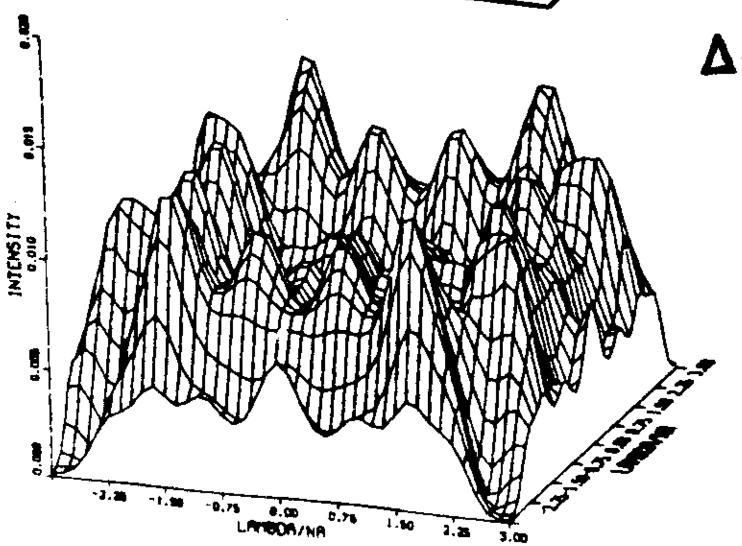
Astigmatic focus $W22 = 4\lambda$

tracking error

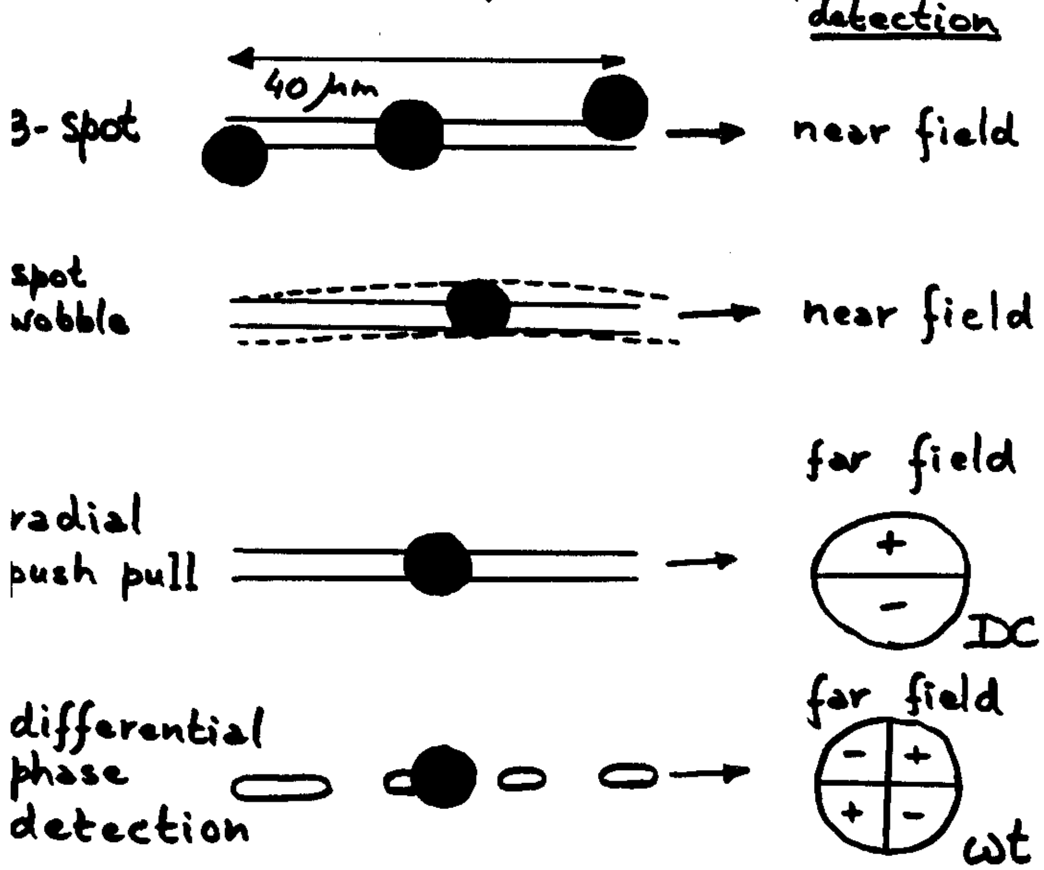
$\Delta v = \frac{q}{4}$

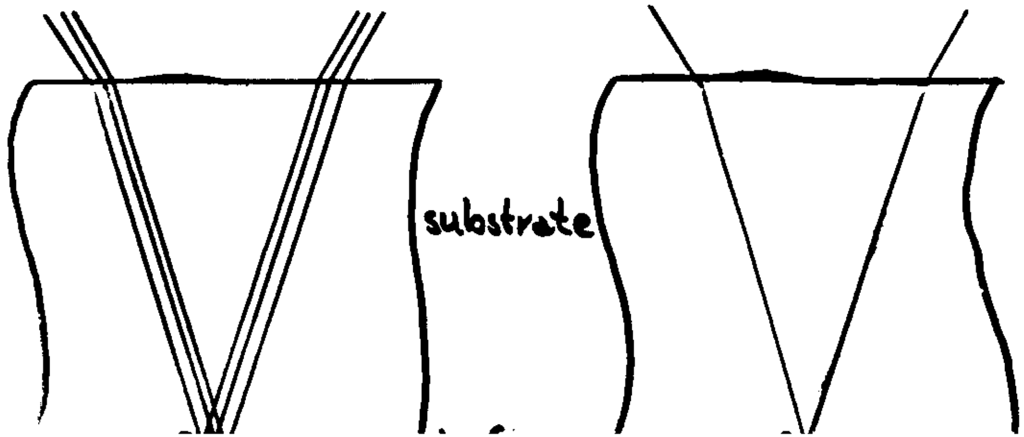


$\Delta v = 0$

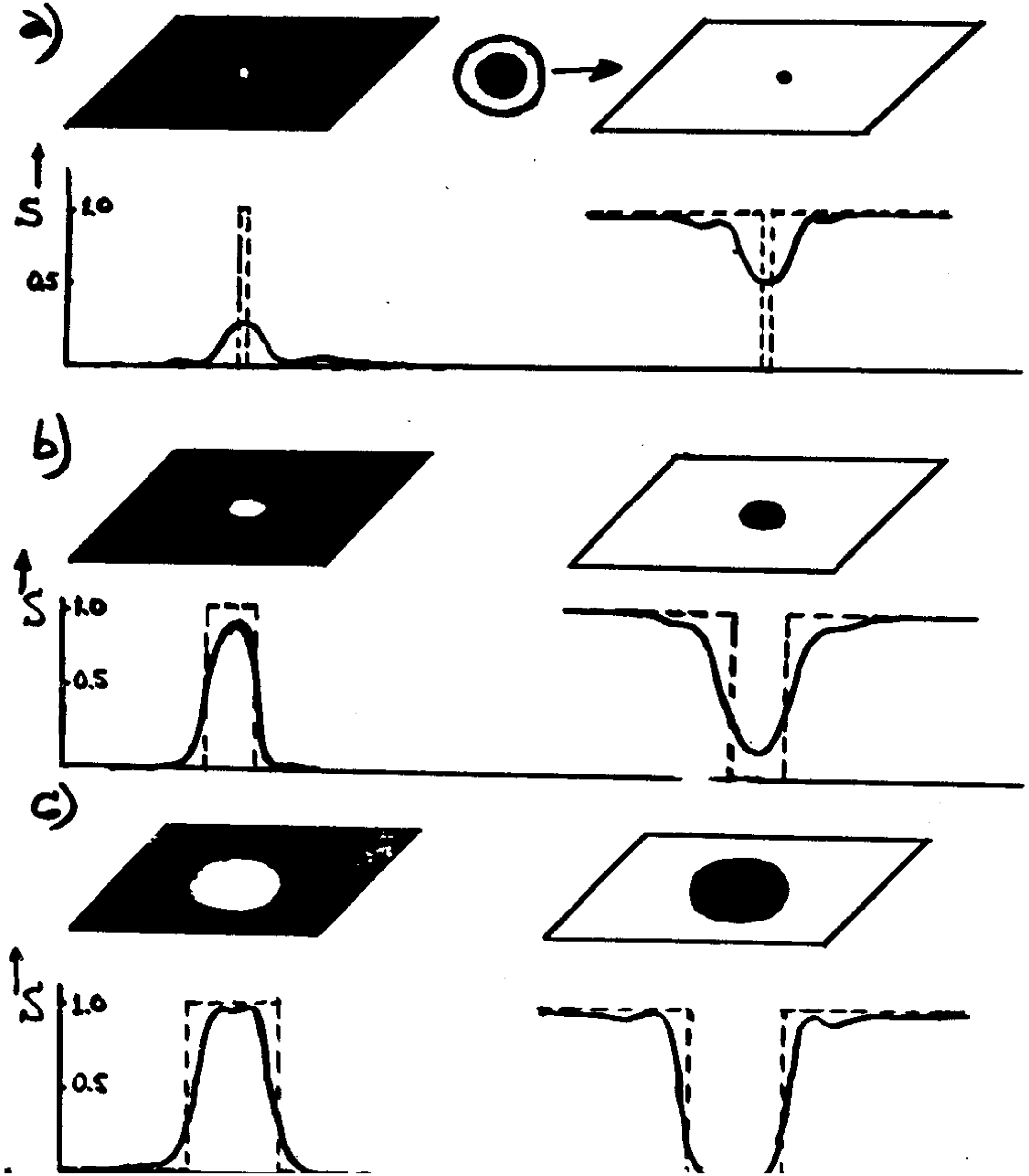


Radial tracking





Effect size ; nonlinearity



Distortion of the signal

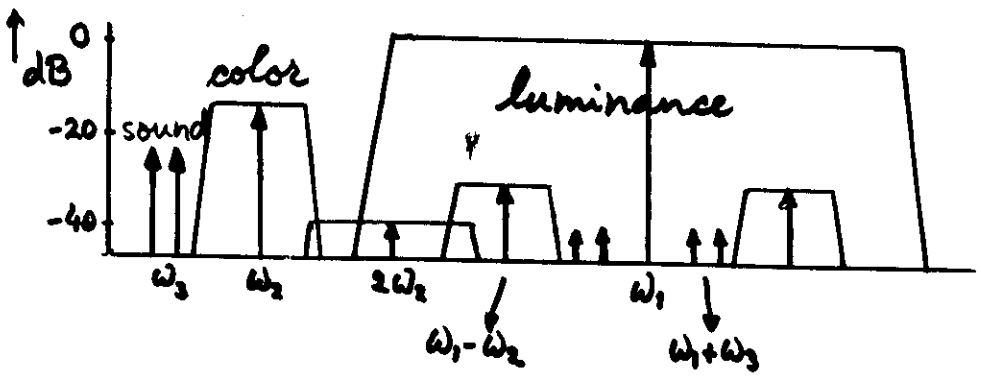
a) Modulated video signal $f(t) \rightarrow$
relief pattern $h(x,y)$

Complex amplitude of the light $a(x,y)$

Detected signal : $|a(x,y)|^2$

$$(1 + a_1 \cos \omega_1 t + b_1 \cos \omega_2 t + c_1 \cos \omega_3 t)^2$$

ω_1 , ω_2 , ω_3 , $\omega_1 - \omega_2$, $\omega_1 - \omega_3$ etc.



b) Cross-talk

- finite track spacing
- tracking errors
- quality of the objective (aberrations)

CD - characteristics

Sound : B = 20 kHz (2x)

Sampling : ≈ 2 times per $\frac{1}{B}$ s

14 bits 16 bits

Dynamic Range : 85 dB 96 dB

Digital noise : $\frac{1}{2}$ smallest bit

Read-out : AlGaAs - laser (780 nm)

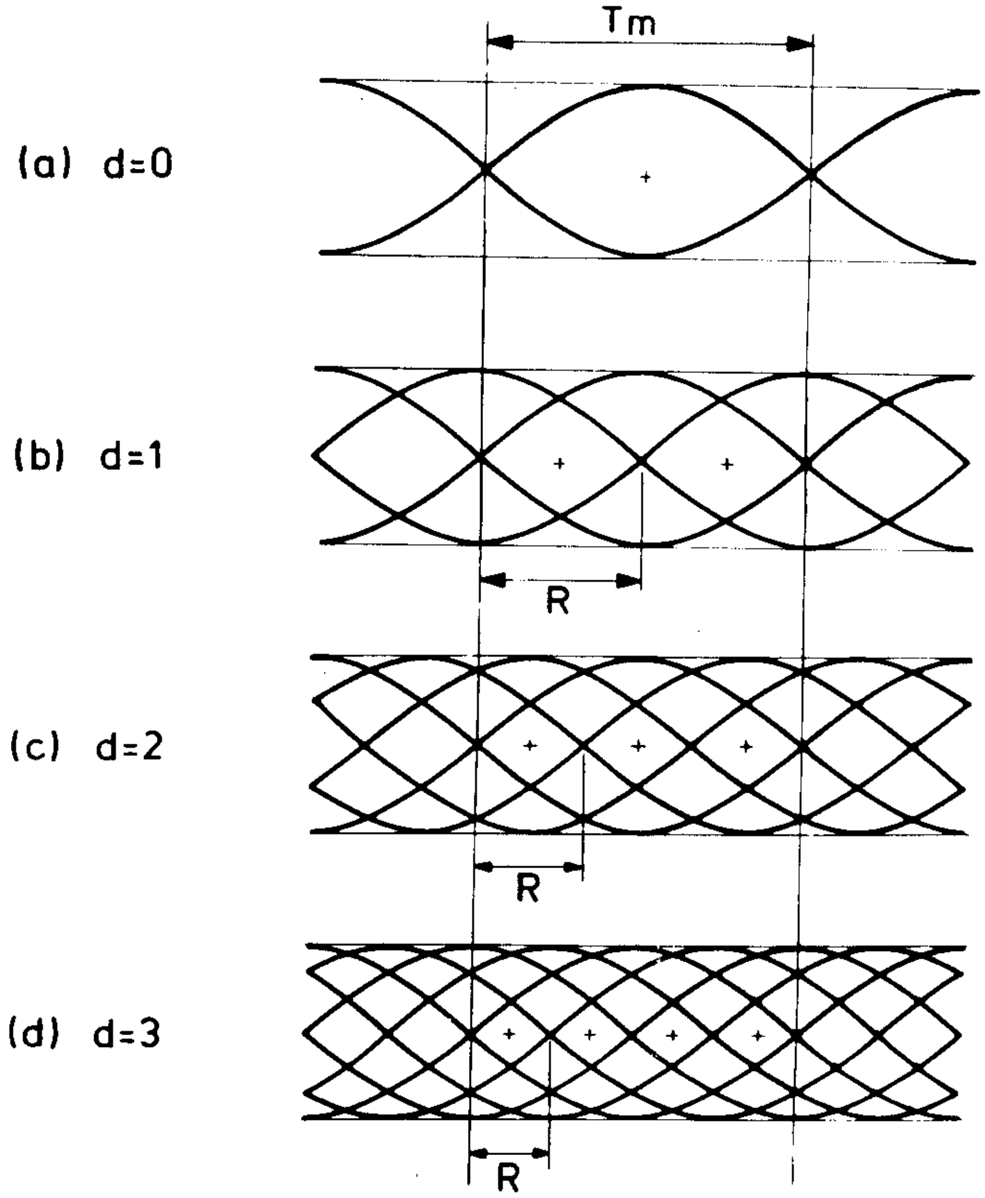
Disc : Φ = 11 cm

70 minutes

constant density

Modulation : EFM

Error corr. : CIRC (cross interleaved Reed/Solomon code)



+ : detection point

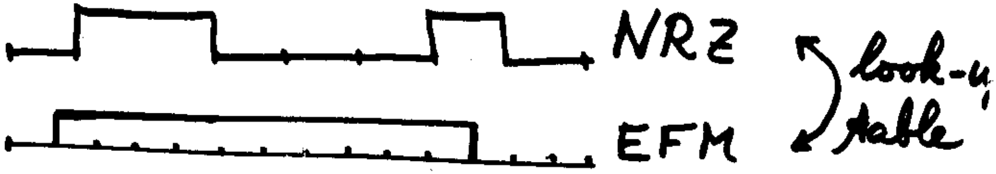
EFM - modulation

Eight to Fourteen Modulation

8 bits

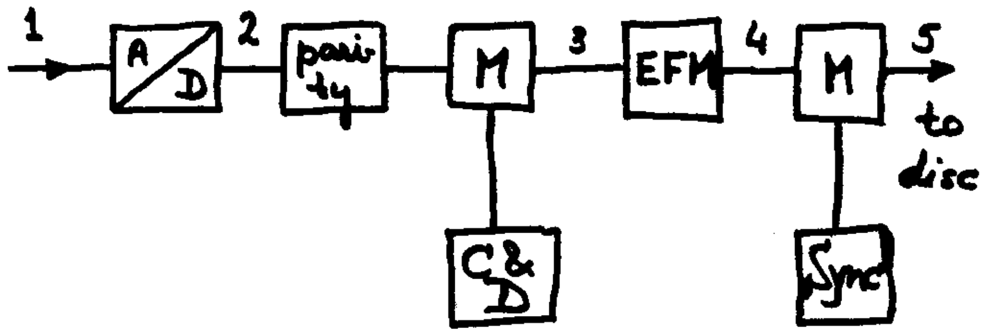
Transform a sequence of 8 bits into a sequence of N bits such that the minimum distance between transients equals 3 bitlengths (maximum < 11)
If N = 14, there are 277 different sequences (only $2^8 = 256$ are needed

Example



Larger 'eye', less sensitive to noise, more sensitive to clock moment

Bitstream



① Analog; two channels 20 kHz each

② 2 x 16 x 44,1 kbit/s = 1,4 Mbit/s

③ 1,4 x ② = 2,0 Mbit/s

④ $\frac{17}{8}$ x ③ = 4,25 Mbit/s

⑤ 4,3218 Mbit/s

Error correction : + 30 %

Efficiency EFM : 0,5

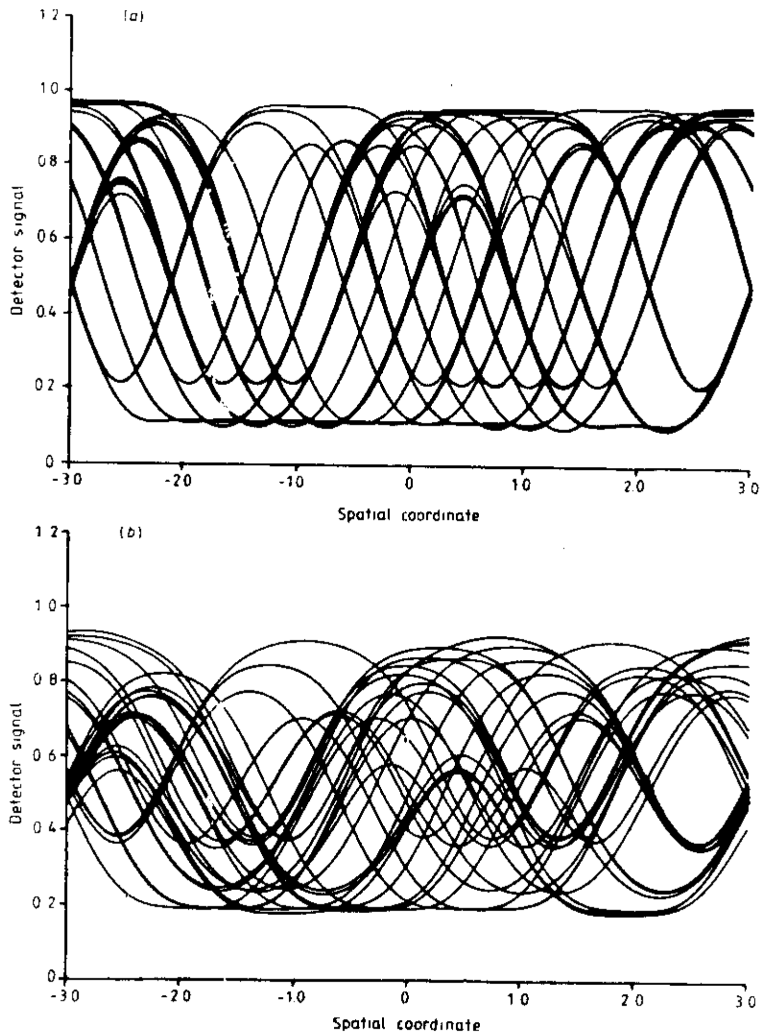


Figure 2.39 The calculated digital eye pattern that is obtained by superimposing the detector signals generated by a certain number of different pit sequences on the disc. These sequences all obey the EFM modulation scheme that has been adopted for the Compact Disc system. The distance between two transients (the eye width) is 0.3 μm. The unit along the horizontal scale is 1 μm. (*a*) For a perfect optical read-out system. (*b*) The scanning spot is astigmatic.

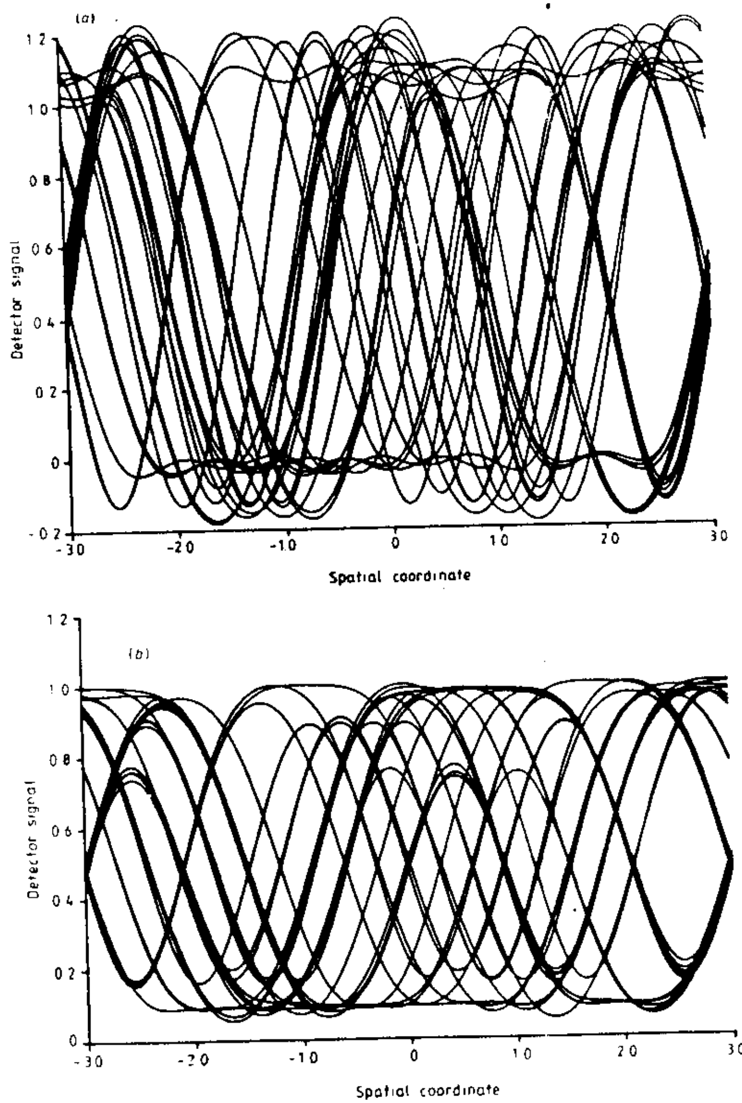
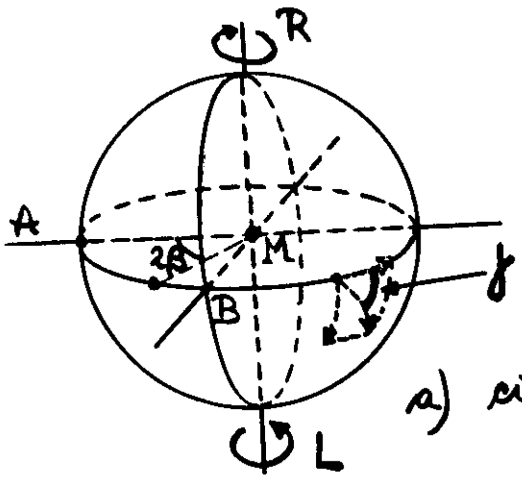


Figure 2.42 The same legend applies as for figure 2.39 but now with the equalising filter added to the detection circuit. (*a*) The ideal scanning spot. (*b*) The astigmatic line.

Kerr (Faraday) rotation and ellipticity

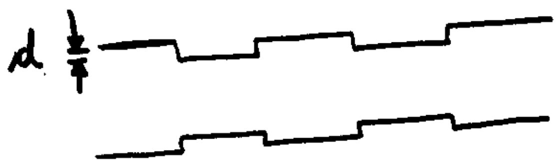


Poincaré sphere

path length difference for LHC and RHC light

a) circular birefringence = Kerr rotation

b) circular partial polariser = Kerr ellipticity

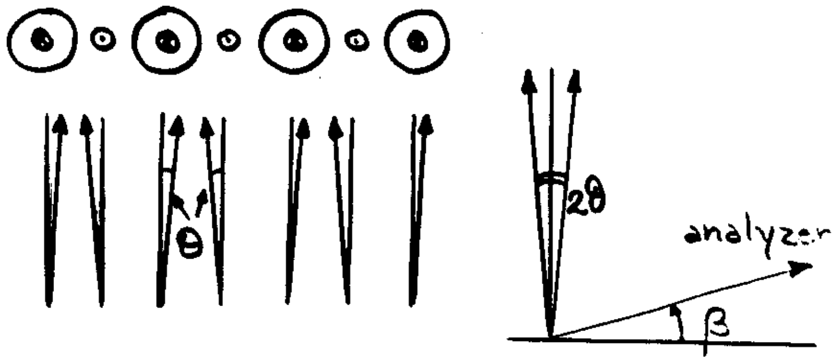


$\vec{M}$ ↑ ↓ ↑ ↓ ↑

$d = \frac{2\theta}{2\pi}\lambda$

$d_{noise} \simeq 30\,Å$; $\phi = 0.015$ | $\theta = 0.006$ → $d \approx 12\,Å$

Detection of magnetic domains



$\theta = 0.006$ rad ($0.35°$) for $Gd_{23}Fe_{77}$

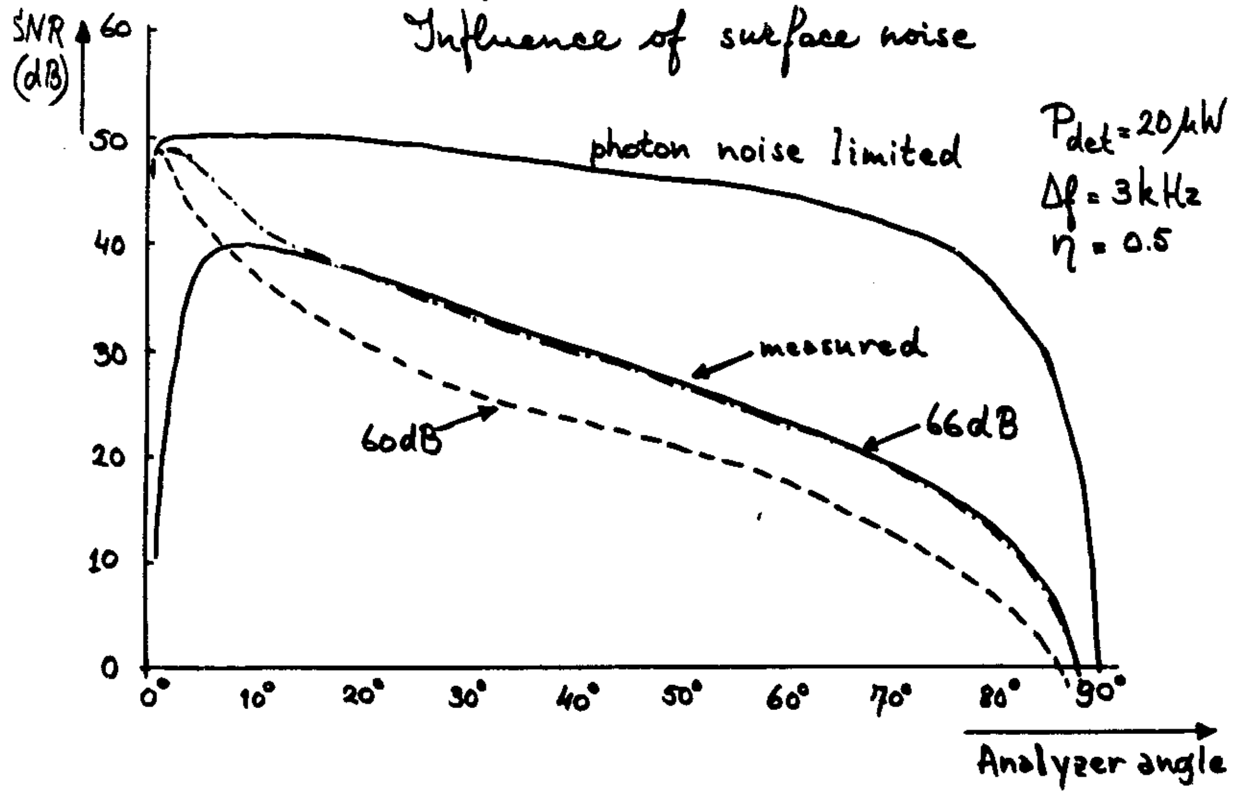
$$i(\beta) = i_0 \sin^2\beta \left[1 + \frac{2\theta}{tg\beta}\mu \cos\omega t\right]$$

($i_0 = 5\,\mu A$ due to $20\,\mu W$ incident optical power; $\lambda = 633$ nm ; $500\,\mu W$ on the disc surface)

Noise sources
a) thermal noise
b) amplifier noise
c) dark current noise
d) photon shot noise
e) surface noise disc

Avalanche-diode : photon noise predominant with respect to a), b) and c).

SNR of magnetic domains
Influence of surface noise



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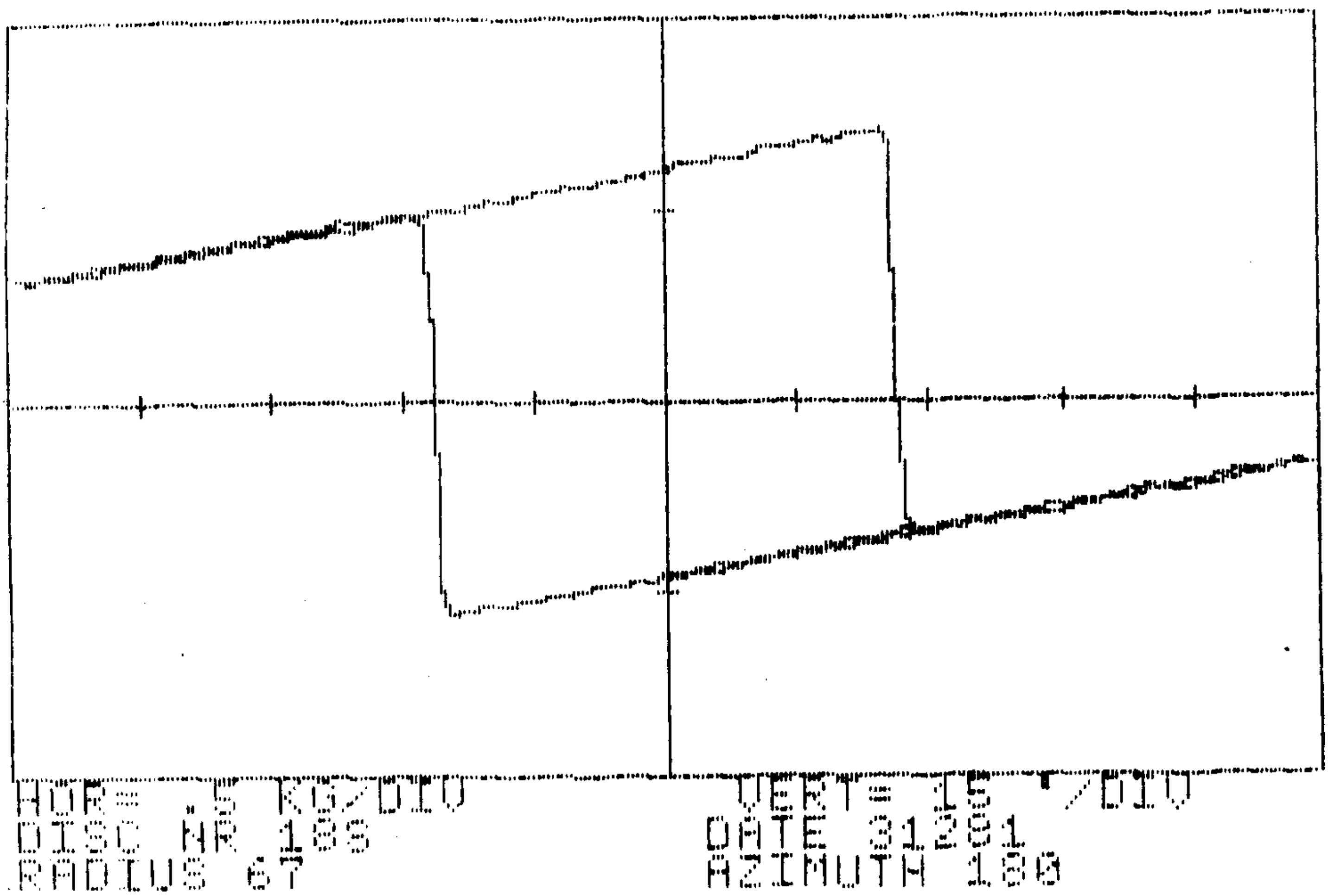

Books

1) J. Isailović
'Videodisc and optical memory systems'
Prentice-Hall, 1985
ISBN 0-13-942053-3
(Signal-oriented)

2. G. Bouwhuis et al.
'Principles of optical disc systems'
A. Hilger, 1985
ISBN 0-85274-785-3
(Optics/servo-oriented)