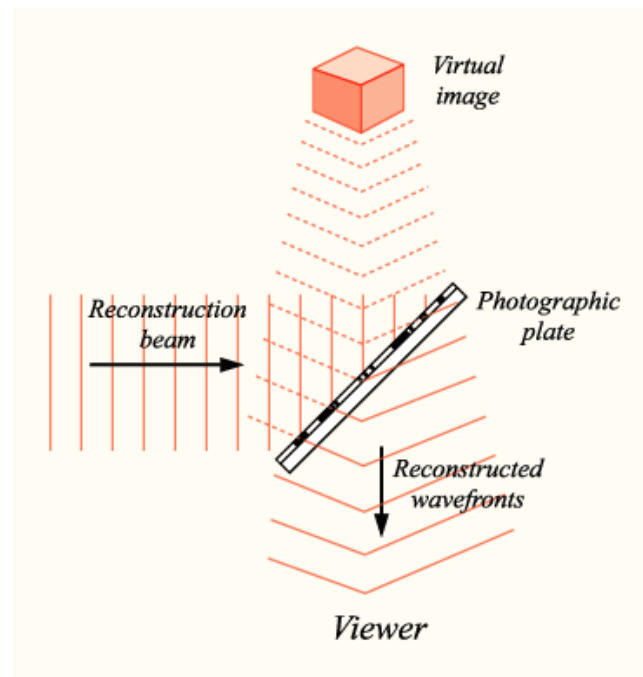
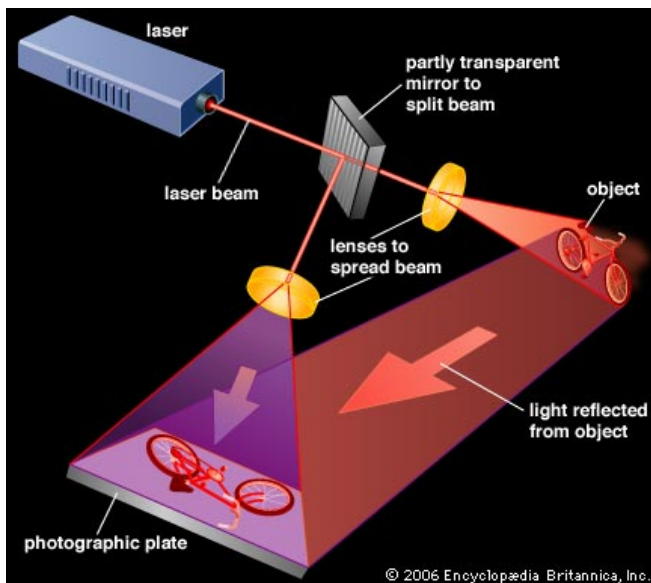


Holography

- Holography mathematics proposed by Dennis Gabor 1948 received Nobel prize in 1972
- Not very practical before laser
needs long coherence length to expose any sizable object
- Emmett Leith & Juris Upatnieks produced first laser hologram
- Hologram: an optical device using photographic techniques and laser light to create a 3 dimensional image
- Holos Greek for complete, and Gram for message
- Makes a complete Intensity and phase copy of the light from a scene
- Regular photograph makes only intensity copy
- With phase added has the same depth information as original
- Setup must have very stable table and lasers



Basic Holographic Setup

- Must have extremely stable, air bearing table: changes $< \lambda$
- Laser must operate in TEM₀₀ mode
- He-Ne, Argon and Krypton most common
- Beam split into two by splitter
- Reference beam reflected by mirror through converging lens to illuminate Photographic Plate
- May be photographic emulsion, photoresist, thermoplastic or dicromated gelatin
- Object beam also spread by converging lens to uniformly illuminate object so light reflects on plate
- Pinholes on lens are spatial filters to remove optical noise from dust and defects in system
- For maximum coherence object and reference path length kept nearly the same.

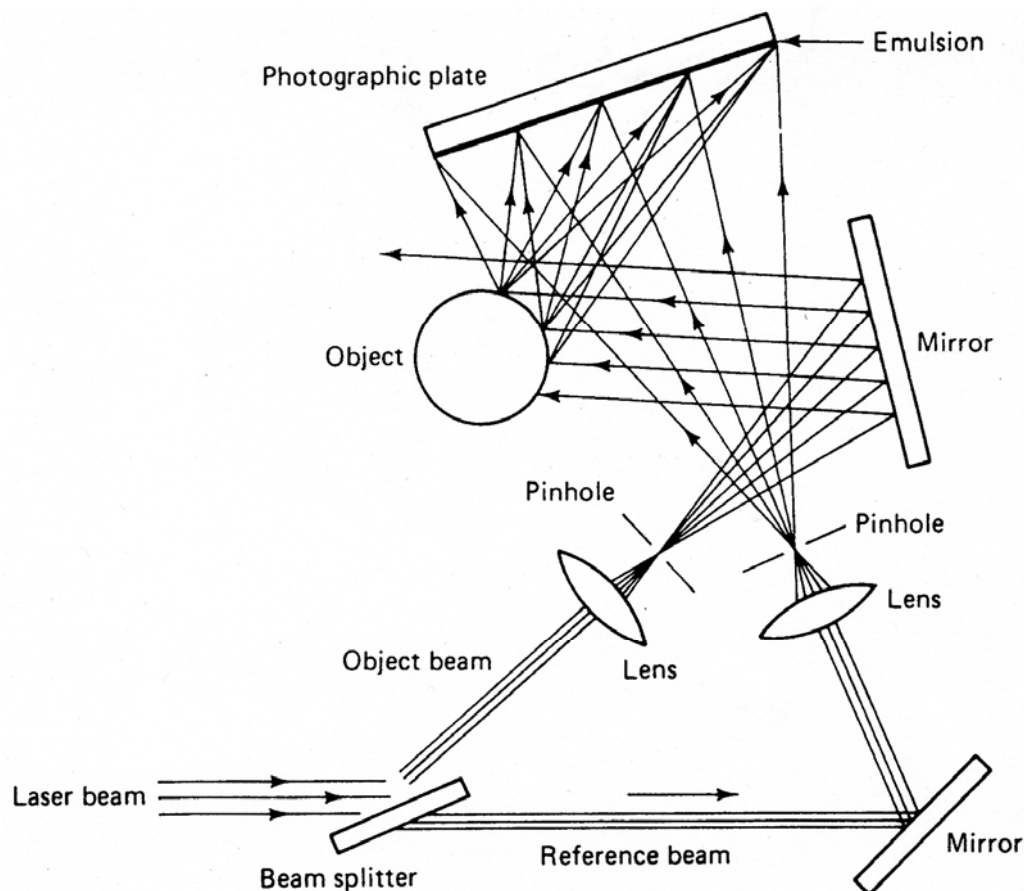


Figure 11-1 Basic optical system for producing holograms.

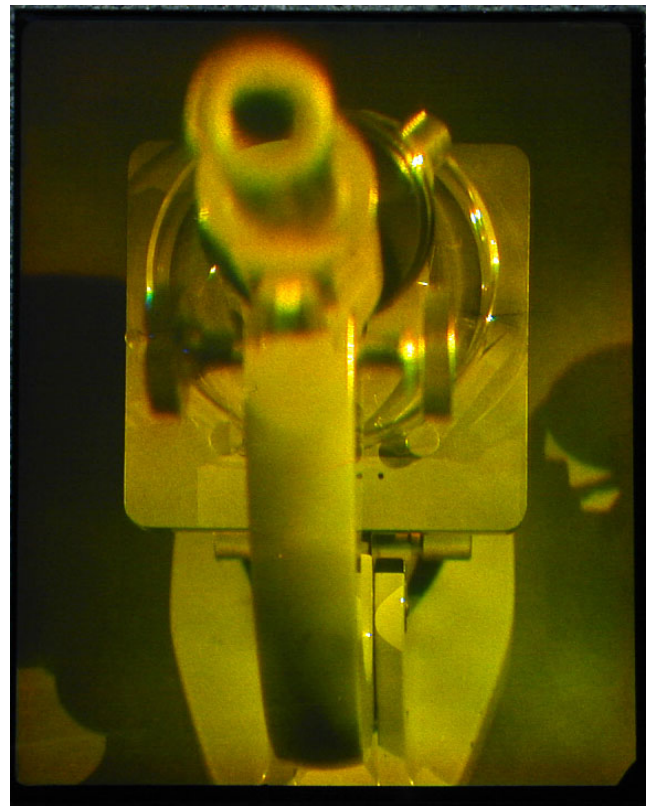
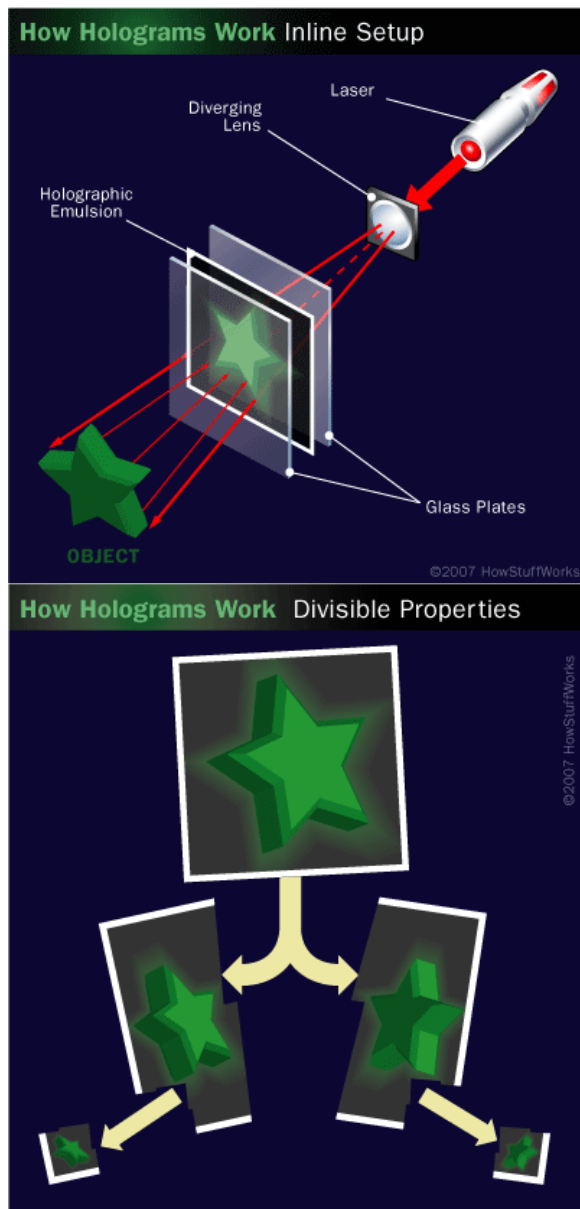
Holograms Very Different from Photographs

Light coming from Hologram

- Light from hologram reproduces light from original scene
- Get 3D image (different image at each eye)
- Thus if focus with lens get same depth of focus behaviour

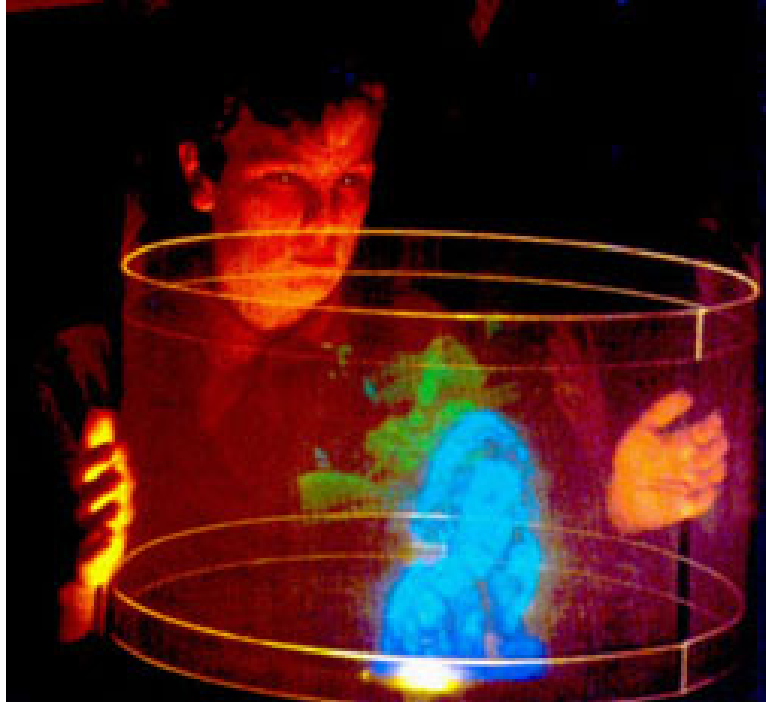
Information Storage

- Information is stored everywhere on the hologram
- Hence if cut hologram in half do not get only half the picture
- Get two holograms which can see object but from different angles
- Also reduced resolution of object
- Note does not work on simple metal holograms



Rotation of Holograms

- If take a hologram and then rotate plate can take another
- Playback image depends on the angle of reference beam then
- Playback of image same as with original reference beam
- Hence rotating hologram can store a movie



Commercial Holograms

Silver Halid Films

- Silver Halid photographic emulsion first holgrams
- Glass plate holograms expensive but best quality
- Hologram there adds a filter that lets regular bright light be used
- Holograms on film plates next best

Photoresist Holograms

- Best now photoresist holograms
- Create patters in photoresist
(organic material whose thickness depends on exposures level)
- Can create colour holograms that way

Metal Film Holograms

- Metal film holograms: make master plate with 3D structure
- Press metal foil (or metal film on plastic) onto master
- Creates hologram with the reflected light (from height of metal)
- Also can do that with press printing

Computer Generated Holograms

- Use computer calculations to get phase/intensity at all points
- Then write with laser in photoresist to create master
- Often used for logo type holograms in metal films



Mathematical Description of Light for Holograms

- Recall that light's electric field vector is written as

$$\vec{E}(z, t) = \hat{i} E_0 \exp[j(-\omega t + kz + \varphi)]$$

where

$$k = \frac{2\pi}{\lambda} \quad j = \sqrt{-1}$$

- The time independent amplitude of the wave is

$$U = \hat{i} E_0 \exp[j(kz + \varphi)]$$

- The time averaged light intensity is given by

$$I = \langle E \bullet E \rangle = \frac{U \bullet U^*}{2Z}$$

- Note: complex conjugate U^*
is beam traveling in opposite direction
where Z is the intrinsic impedance of the medium

$$Z = \sqrt{\frac{\mu}{\epsilon}}$$

Z = intrinsic impedance

μ = permeability of the medium

ϵ = dielectric constant

- For dielectrics it can be shown that

$$Z = \frac{377}{\sqrt{\epsilon_r}} = \frac{377}{n} \Omega$$

Holography Equations

- In the Holographic set up the complex amplitude at the photographic plate

$$U = U_r + U_o$$

- where U_r = the reference beam and U_o = the object beam
- Intensity at the plate is

$$I = \frac{I}{2Z} (U_r U_r^* + U_o U_o^* + U_o U_r^* + U_r U_o^*)$$

- Which becomes

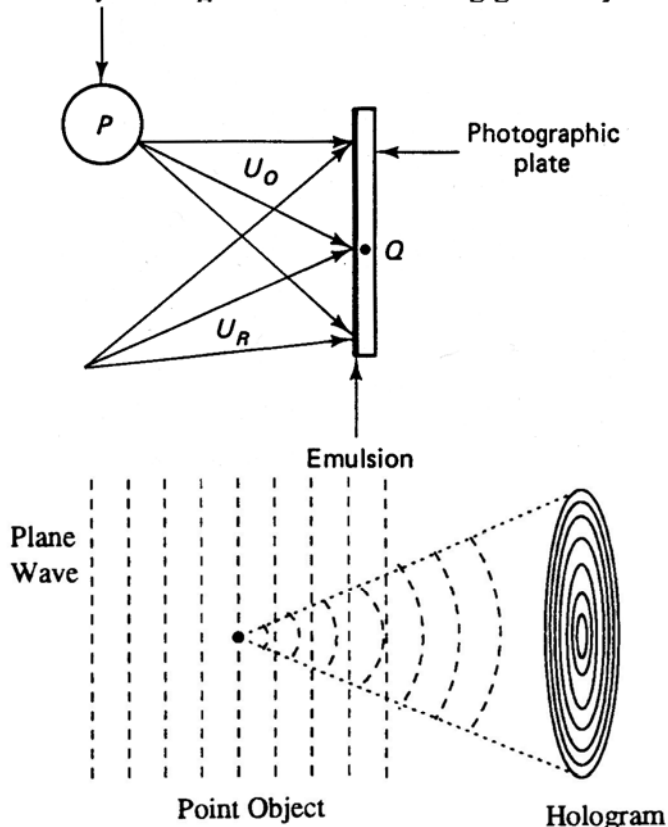
$$I = I_r + I_o + \frac{I}{2Z} (U_o U_r^* + U_r U_o^*)$$

where I_r = intensity (irradiance) from reference

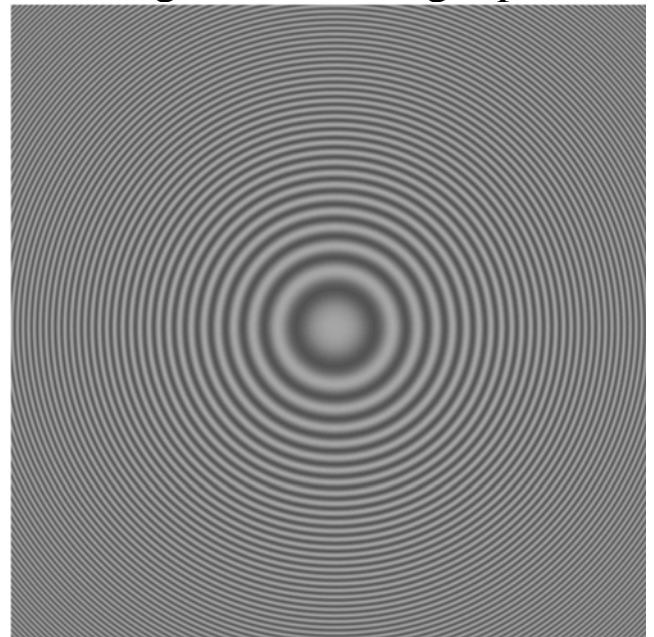
I_o = intensity (irradiance) from object

- As this is a photograph must have the Exposure of the plate = IT where T = time

Object **Figure 11-3** Recording geometry.



Hologram from single point



Absorption Hologram

- Two basic types of Holograms
- Absorption Hologram: darkness in photographic plate
- Phase Hologram: thickness variation in plate
- In Photographic material response curve has linear region
bias reference intensity to linear region
- After development transmittance t_p from plate is

$$t_p = t_0 + \beta \left[I_0 + \frac{I}{2Z} (U_o U_r^* + U_r U_o^*) \right]$$

where t_0 = bias point of plate transmittance curve

β = slope of emulsion transmittance curve

- β is negative for negative emulsions

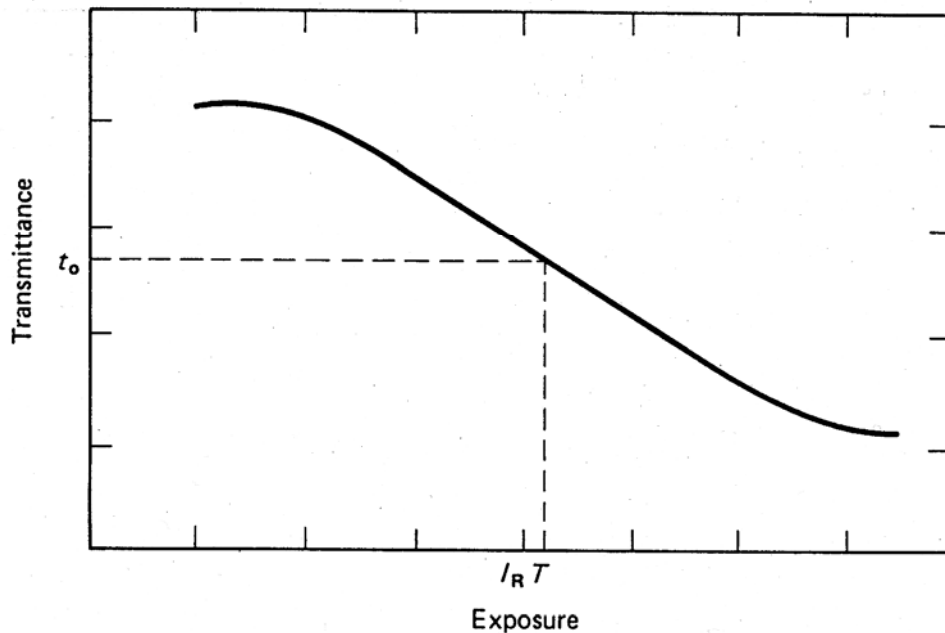


Figure 11-4 Light-amplitude transmittance versus exposure for typical photographic plate used for holography.

Image Creation in Absorption Holograms

- If absorption plate illuminated by a playback laser U_p light transmitted through beam is written as

$$U_p t_p = U_1 + U_2 + U_3 + U_4$$

$$U_1 = U_p t_o$$

$$U_2 = U_p \beta I_o$$

$$U_3 = \frac{U_p U_r^* \bullet U_o}{2Z}$$

$$U_4 = \frac{U_p U_r^* \bullet U_o}{2Z}$$

- Note: each of these is in different direction
- U_1 is light transmitted straight through hologram
- U_2 is light diffracted to small angle
from low frequency interference of light at plate from object
- U_3 & U_4 light forming holographic images

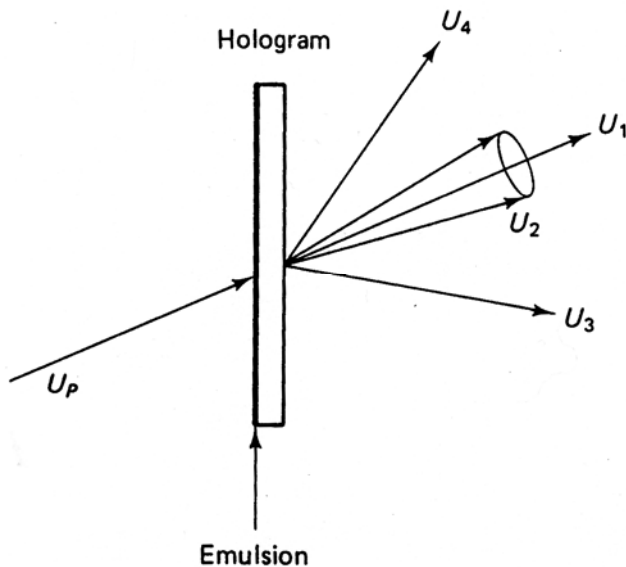


Figure 11-5 Light transmitted and diffracted by a hologram when illuminated with a playback beam.

Hologram Virtual Image Reconstruction

- Virtual image (appears behind hologram) if playback beam differs from reference beam only by intensity

$$U_p = bU_r$$

where b = some constant

- Diffracted light is then

$$U_3 = b\beta I_r U_o$$

where I_r = reference beam intensity

U_o = object beam intensity

- Thus output is exact duplicate of original
see light as though it comes from the object
- Result is true 3D image
- If playback wavelength λ_p different than original hologram λ_h
- Image magnified by

$$M = \frac{\lambda_p}{\lambda_h}$$

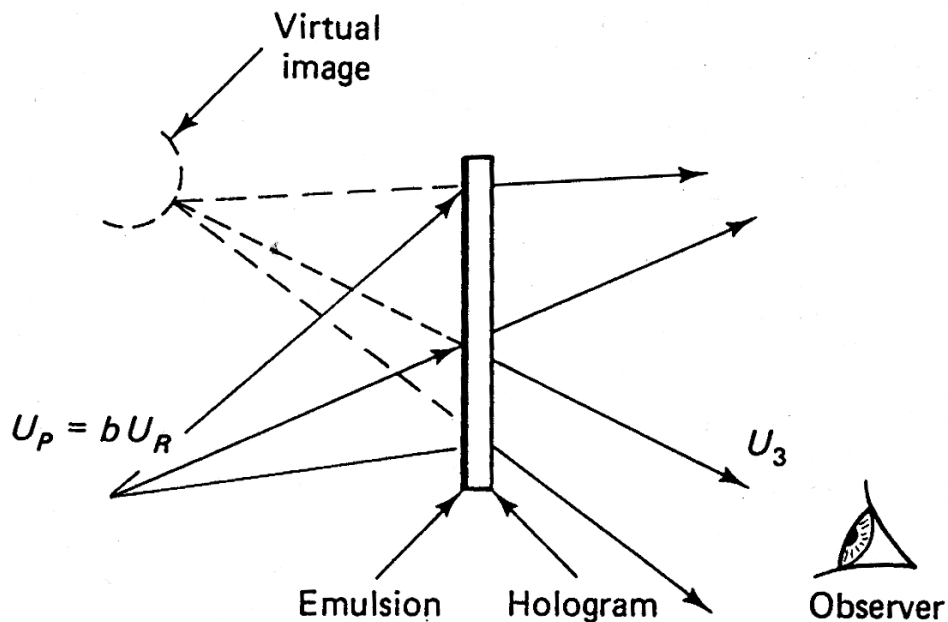


Figure 11-6 Virtual image reconstruction.

What Does a Hologram Look Like

- Consider a hologram of a simple image (letters)
- Hologram as viewed in regular light has noisy looking image
- In playback with laser illumination get original image

SA
TW



Amplitude



Phase Hologram



Playback image from hologram

Hologram Real Image Reconstruction

- If run reference in opposite direction to original then

$$U_p = bU_r^*$$

where b = some constant

- Then reference is complex conjugate to original
- Diffracted light is now

$$U_4 = b\beta I_r U_o^*$$

where I_r = reference beam intensity

U_o^* = object beam travelling backward

- Thus output is original object beam travelling backward becomes a real image (can be projected on surface)
- Again result is true 3D image

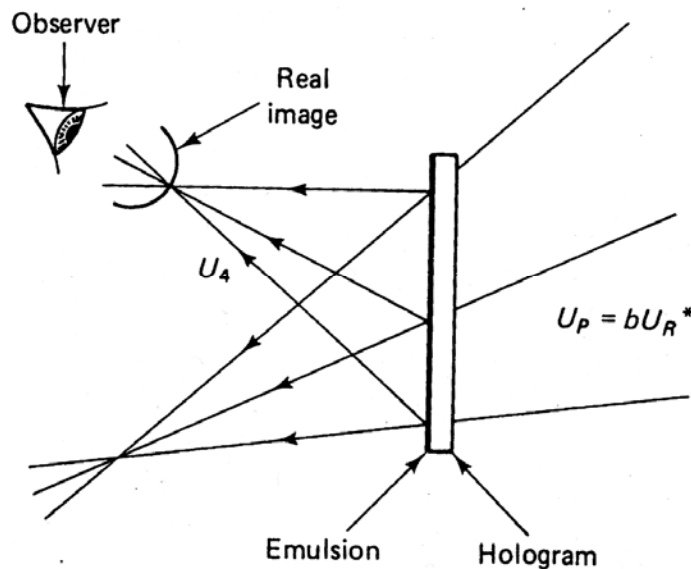


Figure 11-7 Real image reconstruction.

Phase Holograms

- Consist of clear plate where thick varies
- Created from thermoplastic (affected by heat)
dichromatic gelatin - thickness depends on intensity
- Consider the reference and object beams again:
They differ only in intensity and phase
- Let the phase difference from a give point be ϕ

$$U_r = A \quad U_o = a \exp(j\phi)$$

- Then the intensity becomes

$$I = I_r + I_o + \frac{I}{2Z} [Aa \exp(j\phi) + Aa \exp(-j\phi)] = I_r + I_o + \frac{Aa}{2Z} \cos(\phi)$$

- Assume intensity becomes a variation in thickness

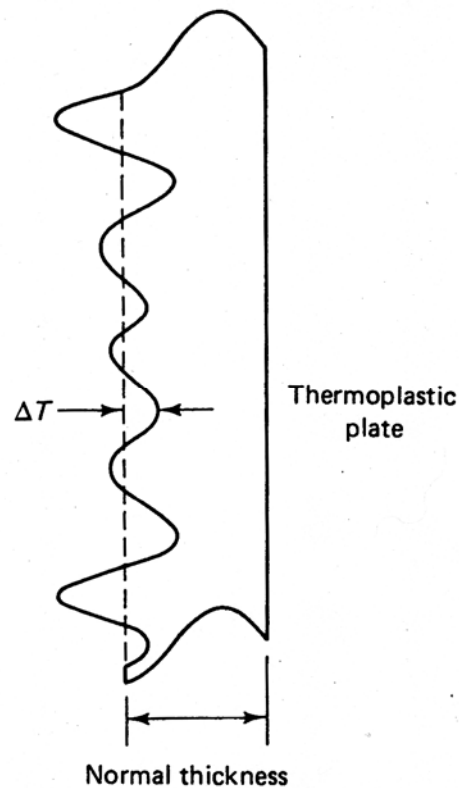


Figure 11-8 Variation of thermoplastic plate thickness due to holographic recording.

Phase Holograms Playback

- Effective thickness of the plate depends only on the changing term

$$\Delta T = -\gamma \Delta I = -\gamma \frac{Aa}{2Z} \cos(\varphi)$$

where γ = photosensitivity constant of the plastic

- The phase change caused for light passing through the plate

$$\Delta \psi = k(n-1)\Delta T = -k(n-1)\gamma \frac{Aa}{2Z} \cos(\varphi)$$

- Applying the playback beam it can be shown that

$$U_3 = -jk(n-1)\gamma AaI_r \exp(j\varphi) = jCU_o$$

where C = a constant

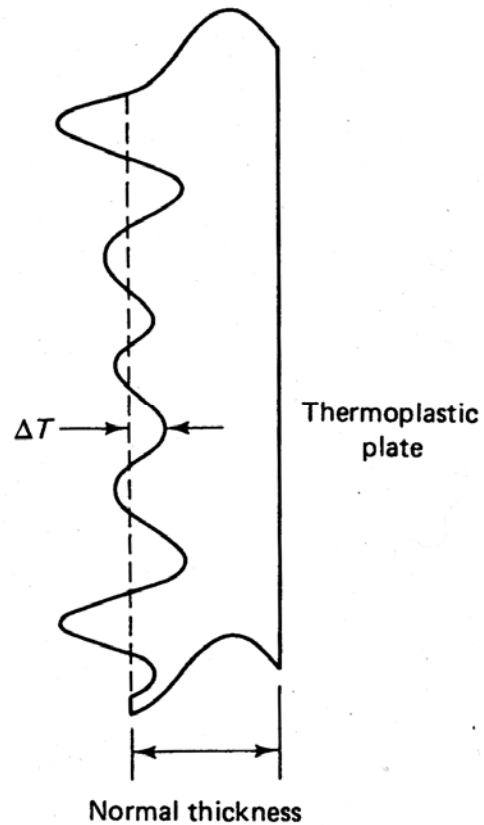


Figure 11-8 Variation of thermoplastic plate thickness due to holographic recording.

Holographic Interferometry

- If take a hologram of an object
then move, distort, displace or change index of refraction
- Then viewing object with hologram creates interference image
- Called a double exposure hologram
- Creates an interference pattern of moved object
- Eg consider a diaphragm displaced from its original position

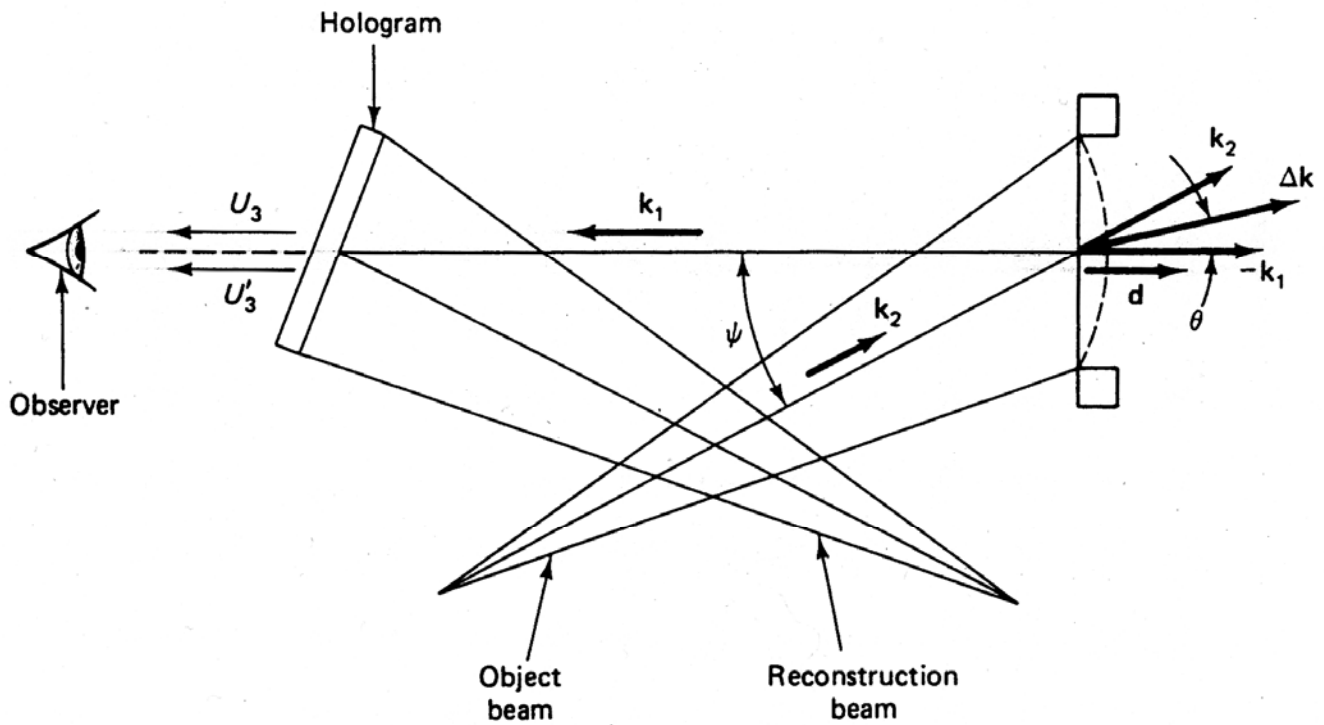


Figure 11-13 System geometry for holographic interferometry.

Holographic Interferometry

- Light from the original hologram playback is

$$U_3 = -U_o$$

- While light from the displaced object

$$U'_3 = -U_o \exp(j\phi)$$

- the phase change is related to the displacement d_p by

$$\Delta\phi = 2kd_p \cos\left(\frac{\psi}{2}\right) \cos(\theta)$$

where ψ = object beam to reflected beam angle

θ = vector difference between object and reflected beam

- Usually $\psi/2 = \theta$

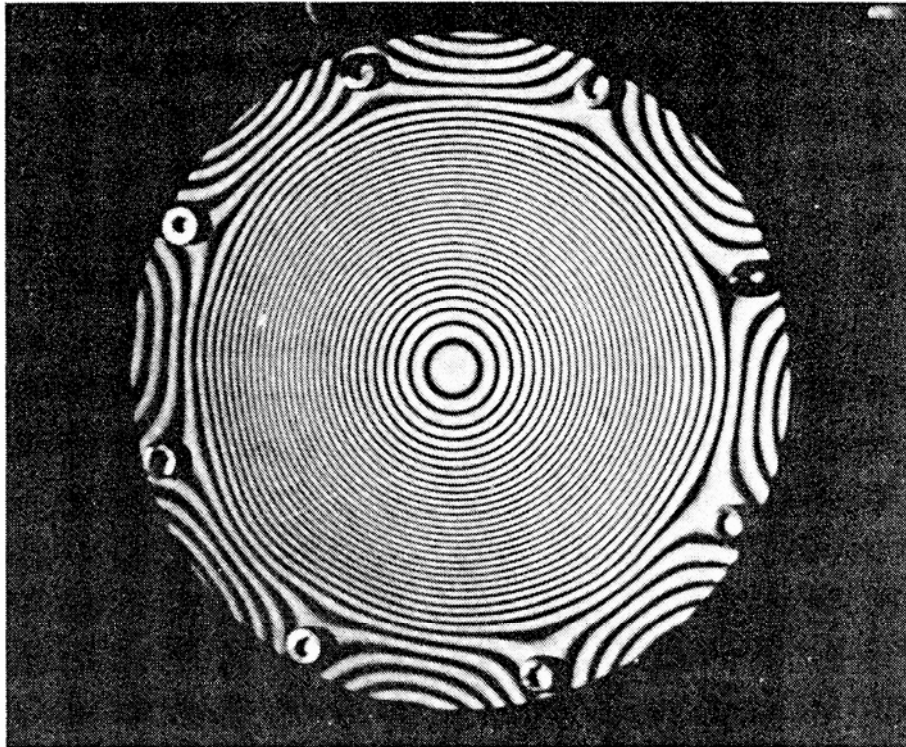


Fig. 6.8 A double exposure holographic interferogram showing the deformation of a circular membrane which has been deformed by uniform pressure. (Photograph courtesy of W. Braga and C. M. Vest, The University of Michigan)

Holographic Interferometry

- The combination of playback and displaced beam is

$$I = 4I_o \cos^2\left(\frac{\Delta\varphi}{2}\right)$$

- Like any interference these have peaks at

$$\Delta\varphi = 2\pi m$$

where $m = \text{integers}$

- A displaced diaphragm will produce concentric rings with displacements

$$d_p = \frac{m\lambda}{2 \cos\left(\frac{\psi}{2}\right) \cos(\theta)}$$

- Note again $\psi/2 = \theta$
- Can use this to trace the change in a structures shape

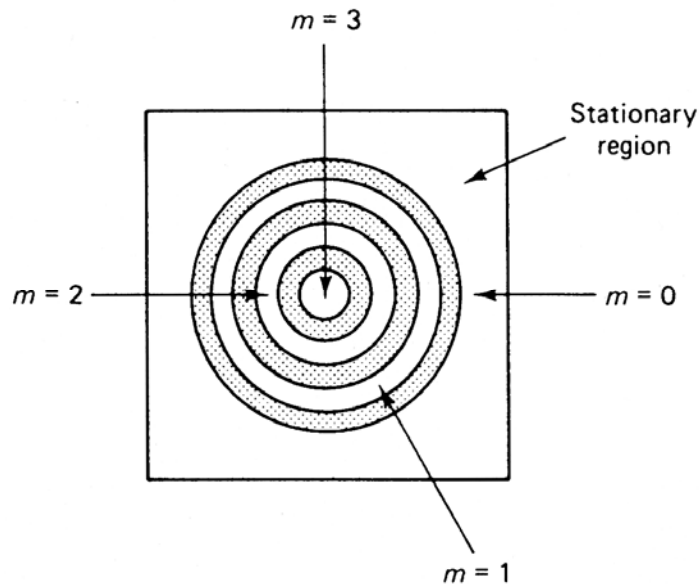


Figure 11-14 Double-exposure holographic image with interference fringes due to normal displacement of the center of a circular diaphragm that is clamped around its perimeter.

2 Plate Holographic Interferometry

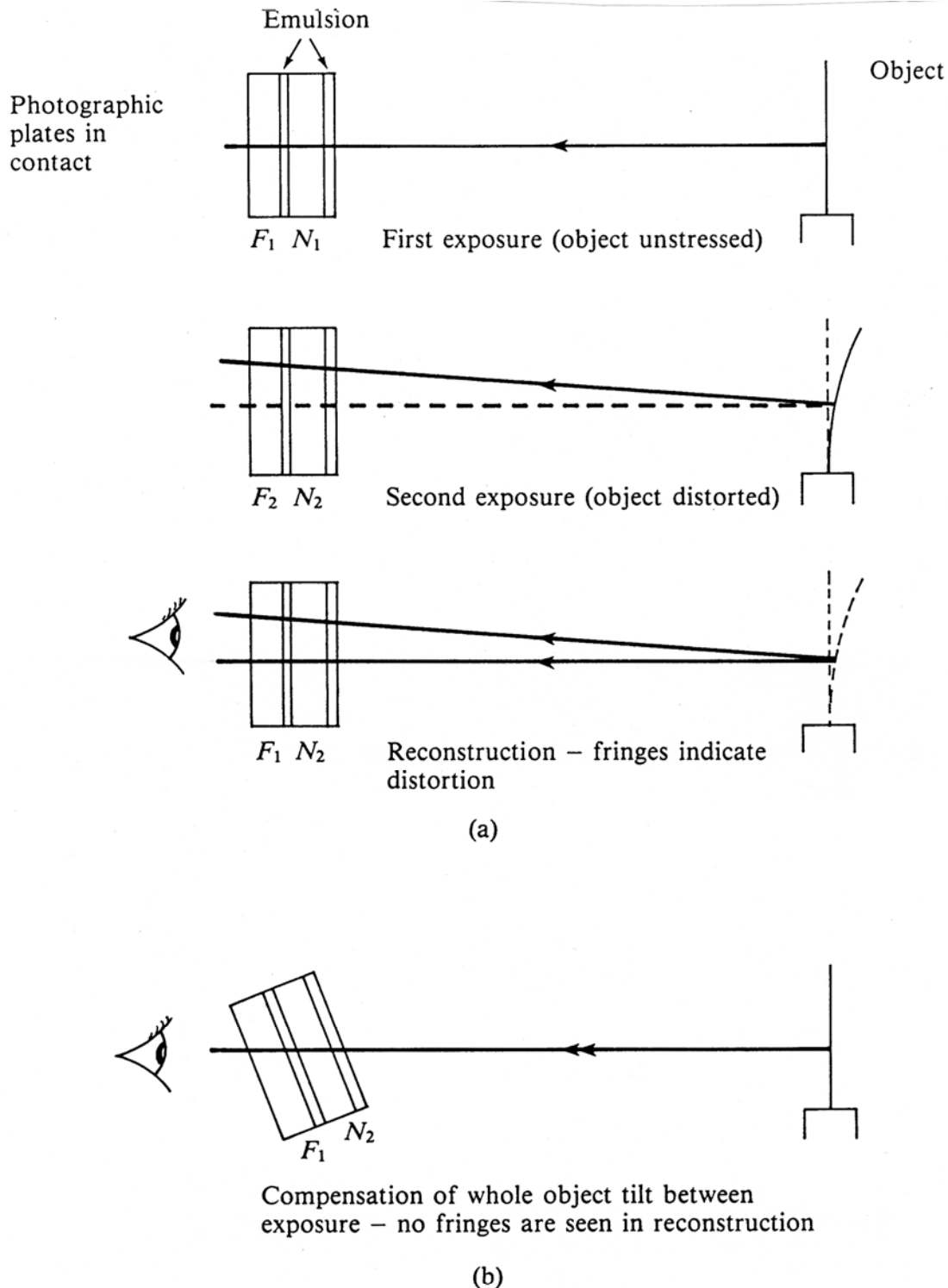


Fig. 6.9 (a) Diagram showing the principles of sandwich holograph: (a) illustrates how the deformation of an object may be determined from the fringe patterns produced by a simultaneous reconstruction of holograms produced at different stages in the deformation of the object; (b) illustrates how a movement of the whole of the object can be compensated for by manipulation of the holograms relative to the reconstructing beam so that no fringes are produced. The identical

Holographic Interferometry of Bent Beam

- Note both vertical and sideways bending seen
- Widely used to determine effects of force on objects
- Compare results to simulations for verifications

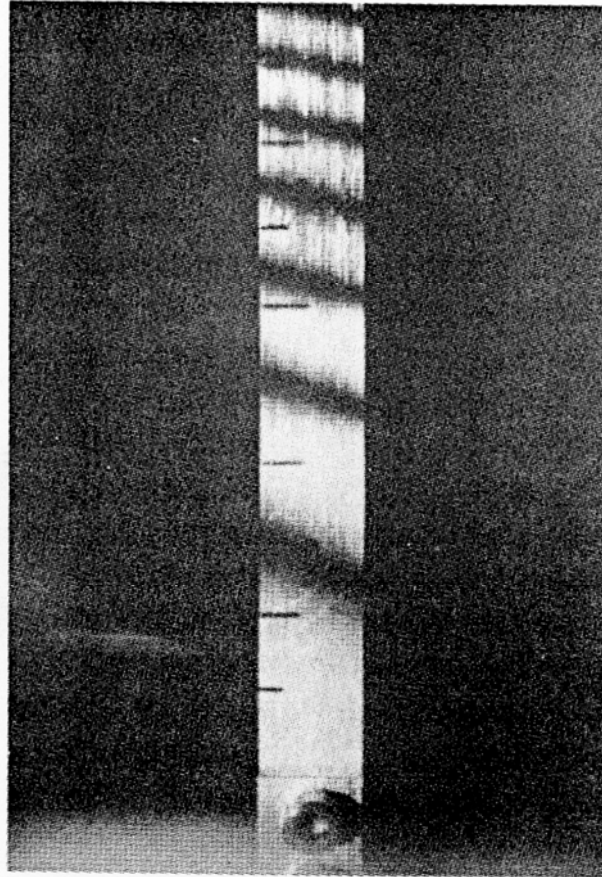


Fig. 6.10 An illustration of real time or single exposure holographic interferometry. Interference of the actual object wave with the reconstructed object wave shows the deformation of the bar. The fact that the fringes are not horizontal indicates that the bar suffers a twist in addition to bending. (From O'Shea/Callen/Rhodes *Introduction to Lasers and their Applications* © 1977 Addison-Wesley, Reading, MA. Fig. 7.14. Reprinted with permission.)

Holographic Optical Elements

- Create hologram of optical element, eg lens, diffraction grating
- Laser light changed by the holographic element in same way as real element
- Because hologram changes direction and phase as in real one
- Only problem is loss of some light
- Eg Holographic diffraction gratings
- Holographic scanners - focus light to a point then rotate scanner to scan point

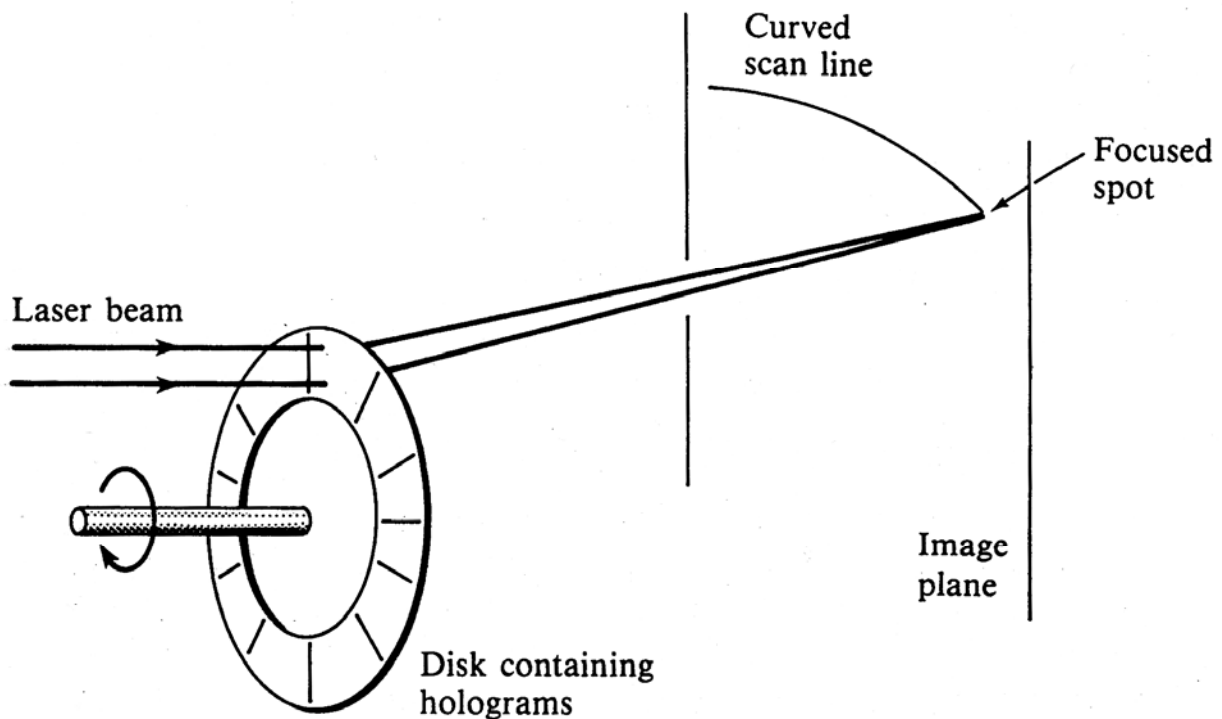


Fig. 6.14 Schematic diagrams of holographic beam scanner, which produces a curved scan line.

