PH 201

OPTICS & LASERS

Lecture_Holography_1

Holography

Dennis Gabor, 1948

Dennis Gabor, inventor of holography, stands beside his 18"x24" laser transmission, pulsed portrait.

The historic portrait was recorded in 1971 by R. Rinehart, McDonnell Douglas Electronics Company, St. Charles, MO to commemorate Gabor's winning of the Nobel Prize that year.

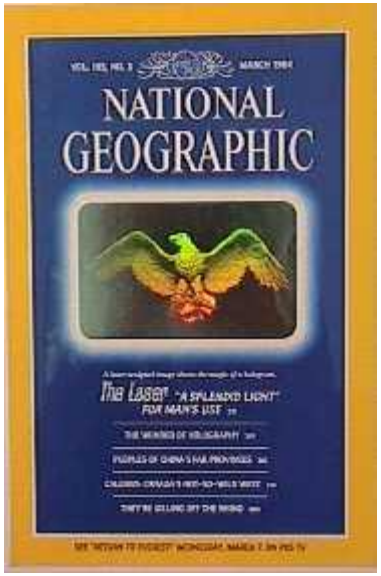
"Train and Bird" is the first hologram ever made with a laser using the off-axis technique.

This pioneer image was produced in 1964 by Emmett Leith & Juris Upatnieks at the University of Michigan only four years after the invention of the laser.

In 1983 MasterCard International, Inc. became the first to use hologram technology in bank card security

The first credit cards to carry embossed holograms were produced by American Bank Note Company, New York, for MasterCard International, Inc. The 2-channel holograms were the widest distribution of holography in the world at that time.

National Geographic magazine was the first major publication to put a hologram on its cover. The March 1984 issue carried nearly 11 million holograms throughout the world.



Volume 165, Number 3, March 1984 had the first hot stamped hologram embossed directly onto a magazine cover, with an accompanying story, "The Wonder of Holography." The 2 1/2" x 4" embossed hologram of an eagle was produced in 1983 by Kenneth A. Haines, Eidetic Images, Inc. Elmsford, NY, a subsidiary of American Bank Note Company, New York, NY. (Photo by Paul D. Barefoot, 1999)

Holography vs. Photography

- A hologram represents a recording of information regarding the light that came from original scene as scattered in a range of directions rather than from only one direction, as in a photograph. This allows the scene to be viewed from a range of different angles, as if it were still present.

- A photograph can be recorded using **normal light sources** whereas **a laser is required to record a hologram**.

- A **lens** is required in photography to record the image, whereas in holography, light from object is **scattered** directly onto the recording medium.

- A holographic recording requires a second light beam (the reference beam) to be directed onto the **recording medium**.

Holography vs. Photography

- A photograph can be viewed in a wide range of lighting conditions, whereas holograms can only be viewed with very specific forms of illumination.
- When a photograph is **cut** in half, each piece shows half of the scene. When a hologram is cut in half, the whole scene can still be seen in each piece.
- A photograph is a 2D representation that can only reproduce a rudimentary 3D effect, whereas the reproduced viewing range of a hologram adds many more depth perception cues that were present in the original scene.
- A photograph clearly maps out light field of original scene. Developed hologram's surface consists of a very fine, seemingly random pattern, which appears to bear no relationship to the scene it recorded.

Conventional vs. Holographic photography

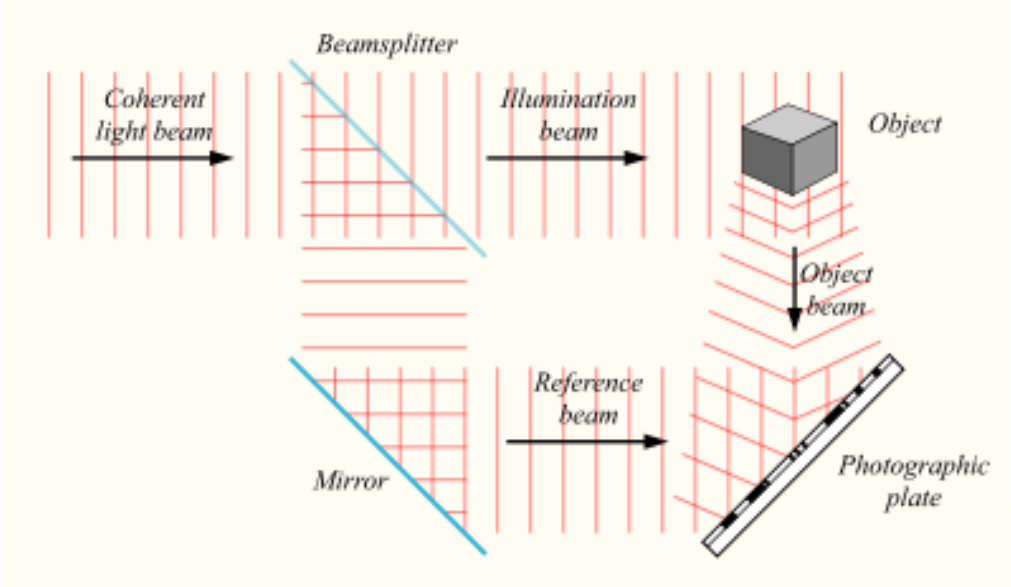
- **Conventional**:
  - 2-d version of a 3-d scene
  - Photograph lacks depth perception or parallax
  - Film sensitive only to radiant energy
  - Phase relation (i.e. interference) are lost

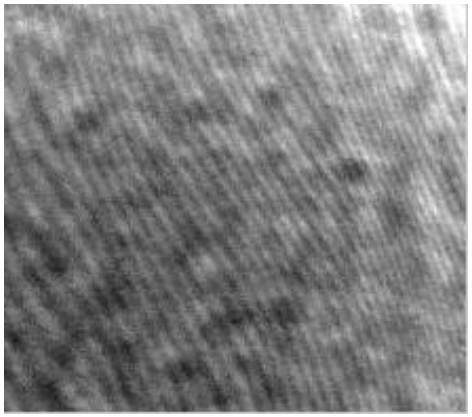
- **Hologram**:
  - Freezes intricate wavefront of light that carries all visual information of scene
  - To view a hologram, wavefront is reconstructed
  - View what we would have seen if present at the original scene through a window defined by the hologram
  - Provides depth perception & parallax

Conventional vs. Holographic photography

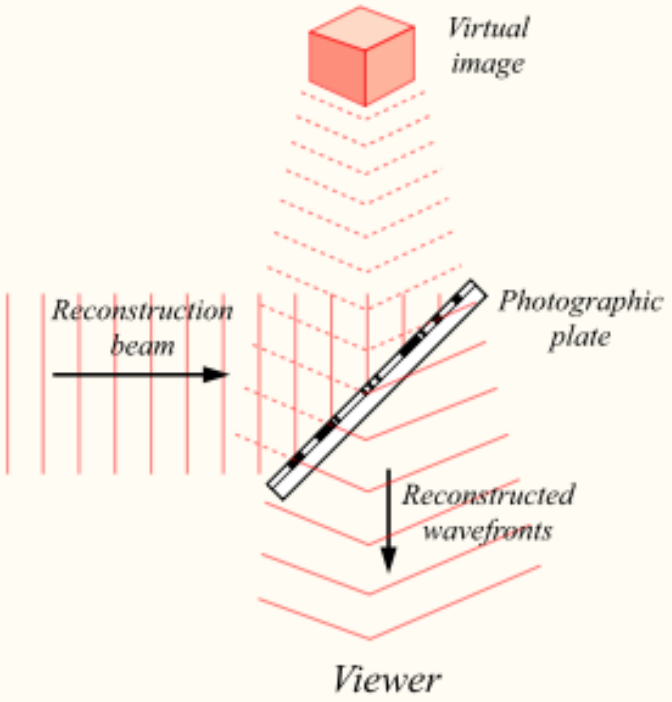
- **Hologram**:
  - Converts phase information into amplitude information
    (in-phase: max. amplitude, out-of-phase: min. amplitude)
  - Interfere wavefront of light from a scene with a reference wave
  - Hologram is a complex interference pattern of microscopically spaced fringes
  - “holos” - Greek for whole message

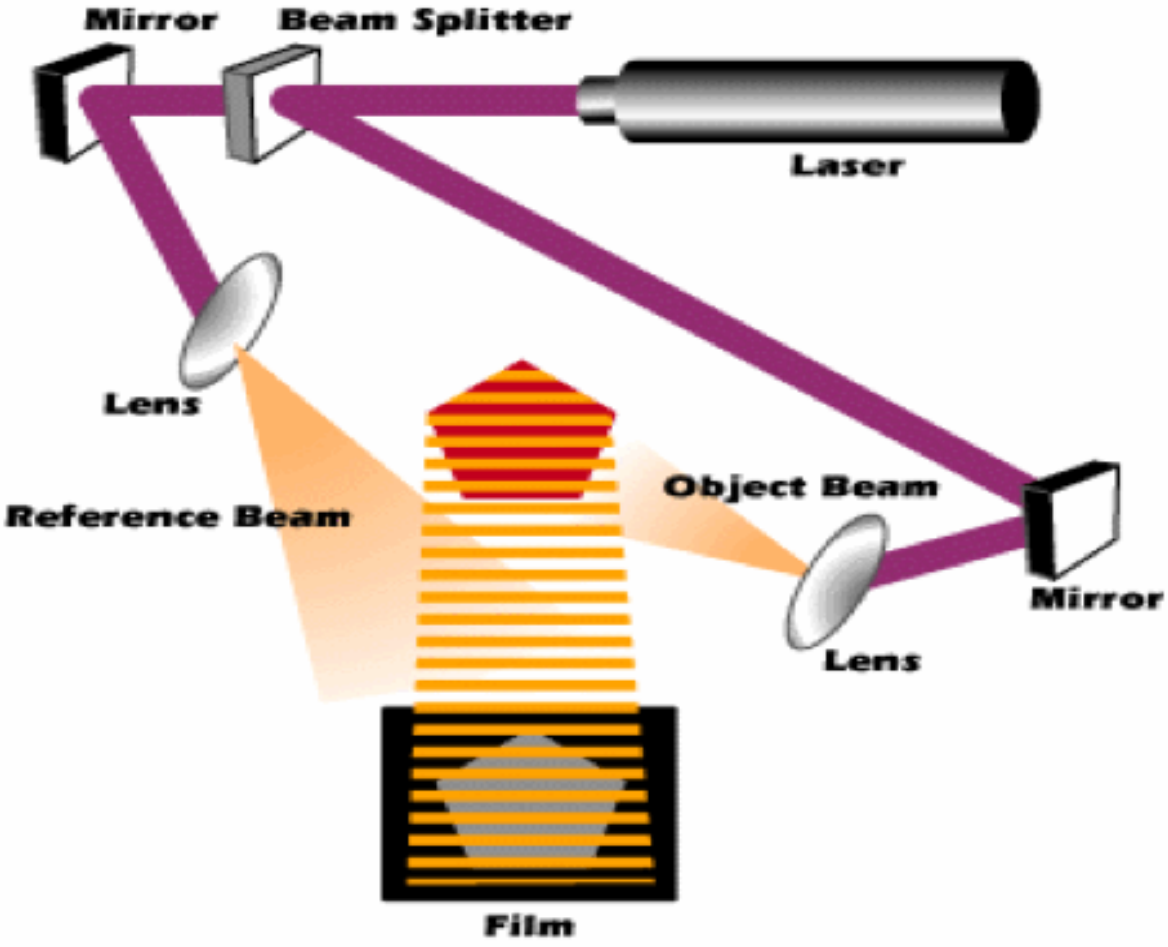
Recording a Hologram



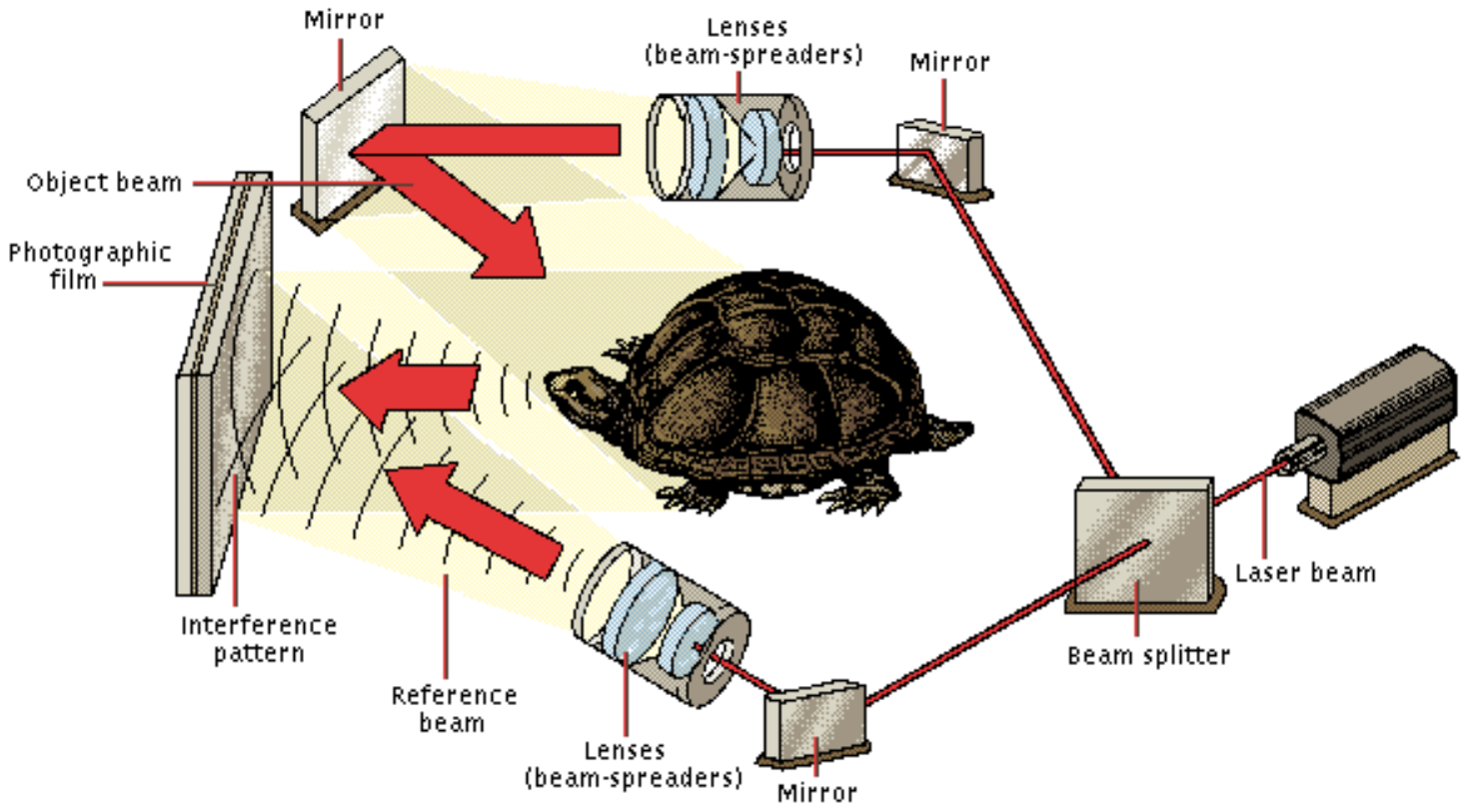


Reconstructing a Hologram




Mirror
Beam Splitter
Laser
Lens
Reference Beam
Object Beam
Mirror
Lens
Film

Making a Hologram



Mathematical Model

- A single frequency light wave can be modeled by a complex no. *U*, which represents electric or magnetic field of light wave. Amplitude & phase of light are represented by absolute value & angle of *U*.

- Object & reference waves at any point in holographic system are given by U_O & U_R. Combined beam is given by (U_O + U_R).

- Energy of combined beam is proportional to square of magnitude of combined wave:

$$\left|U_O + U_R\right|^2 = U_O U_R^* + \left|U_R\right|^2 + \left|U_O\right|^2 + U_O^* U_R$$

- If a photographic plate is exposed to the two beams & then developed, its transmittance, ***T***, is proportional to light energy that was incident on plate.

$$T = kU_O U_R^* + k\left|U_R\right|^2 + k\left|U_O\right|^2 + kU_O^* U_R$$

where *k* is a constant.

Mathematical Model

- When developed plate is illuminated by reference beam, light transmitted through the plate, U_H, is equal to transmittance ***T*** multiplied by reference beam amplitude U_R,

$$U_H = TU_R = kU_O U_R U_R^* + k|U_R|^2 U_R + k|U_O|^2 U_R + kU_O^* U_R U_R$$
$$= kU_O|U_R|^2 + k|U_R|^2 U_R + k|U_O|^2 U_R + kU_O^* U_R^2$$

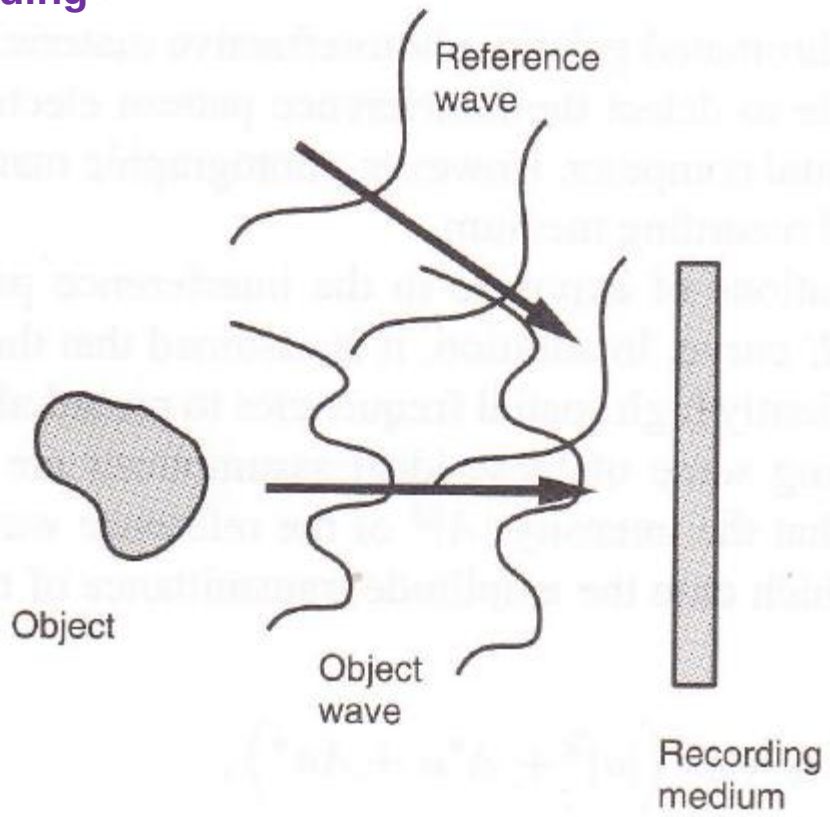
- U_H has four terms, each representing a light beam emerging from hologram.

- 1st term is proportional to U_O. This is reconstructed object beam which enables a viewer to see original object even when it is no longer present in field of view.

- 2nd & 3rd beams are modified versions of reference beam.

- 4th term is known as ***conjugate object beam***. It has the reverse curvature to the object beam itself and forms a real image of the object in the space beyond the holographic plate.

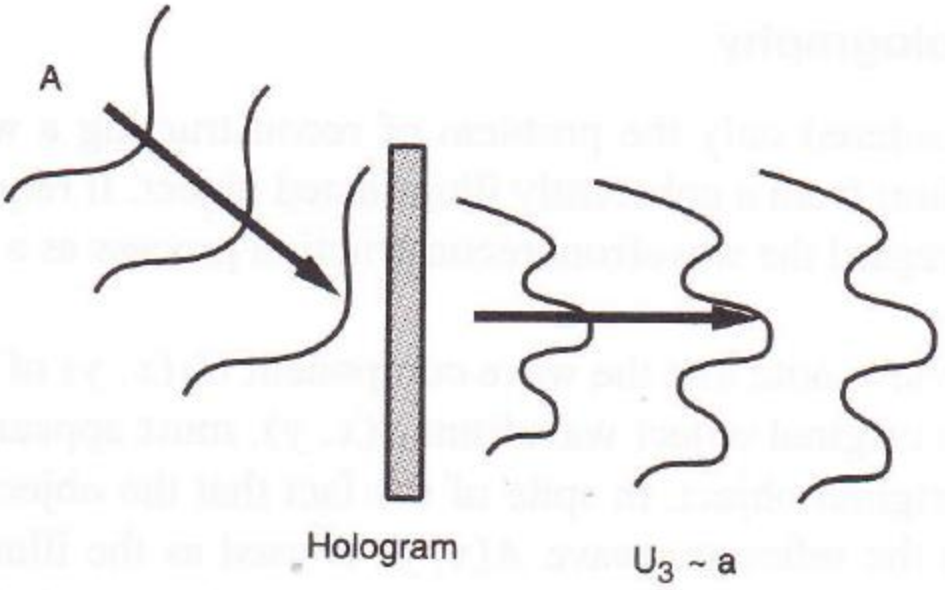
Interferometric recording



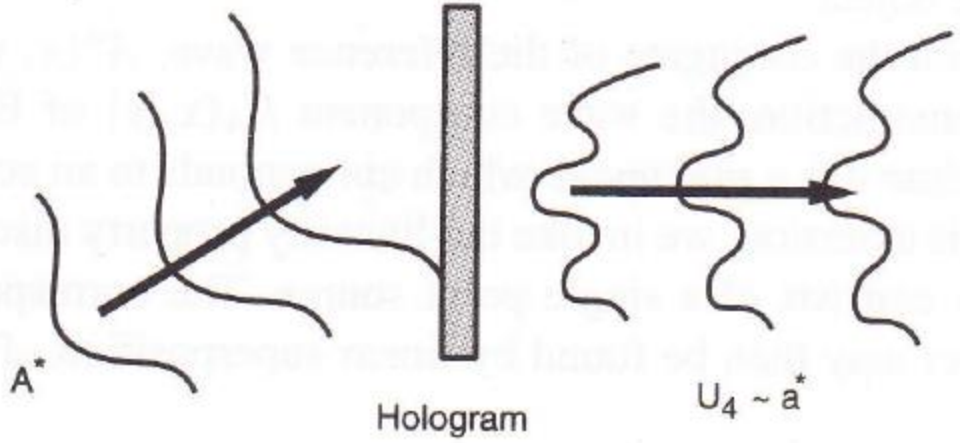
$$a(x, y) = |a(x, y)| \exp[j\phi(x, y)]$$

$$A(x, y) = |A(x, y)| \exp[j\psi(x, y)]$$

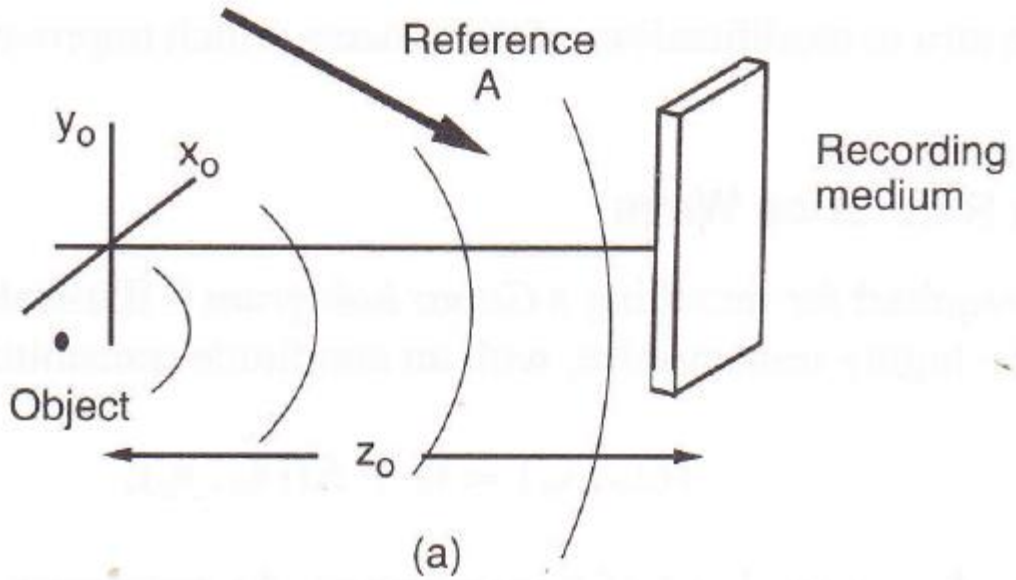
$$\mathcal{I}(x, y) = |A(x, y)|^2 + |a(x, y)|^2 + 2|A(x, y)|\,|a(x, y)| \cos[\psi(x, y) - \phi(x, y)]$$

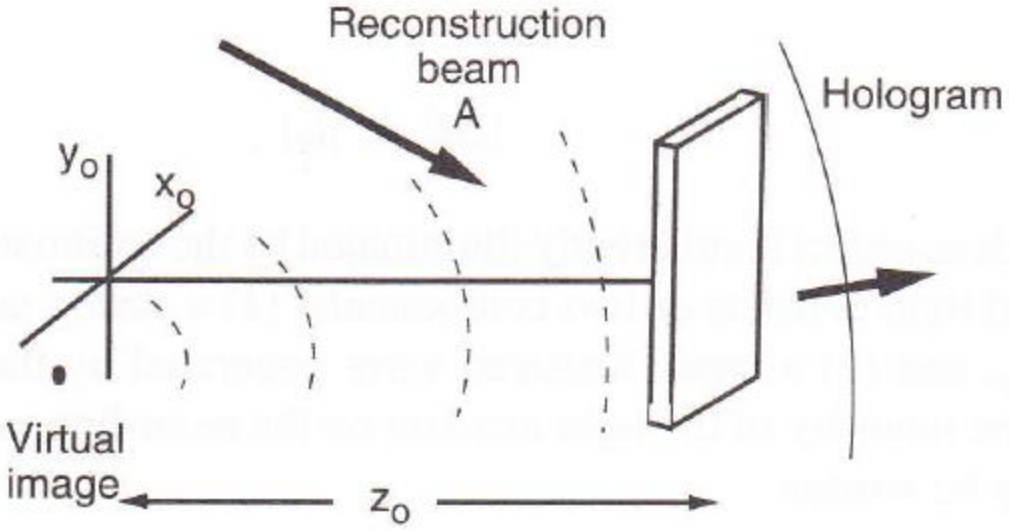


(a)

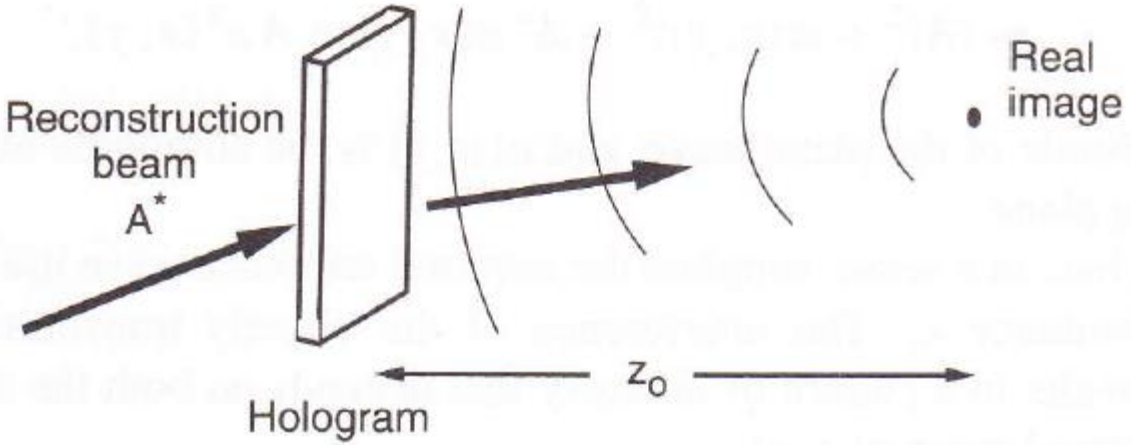


(b)


Reference
A
y_o
x_o
Recording
medium
Object
z_o
(a)

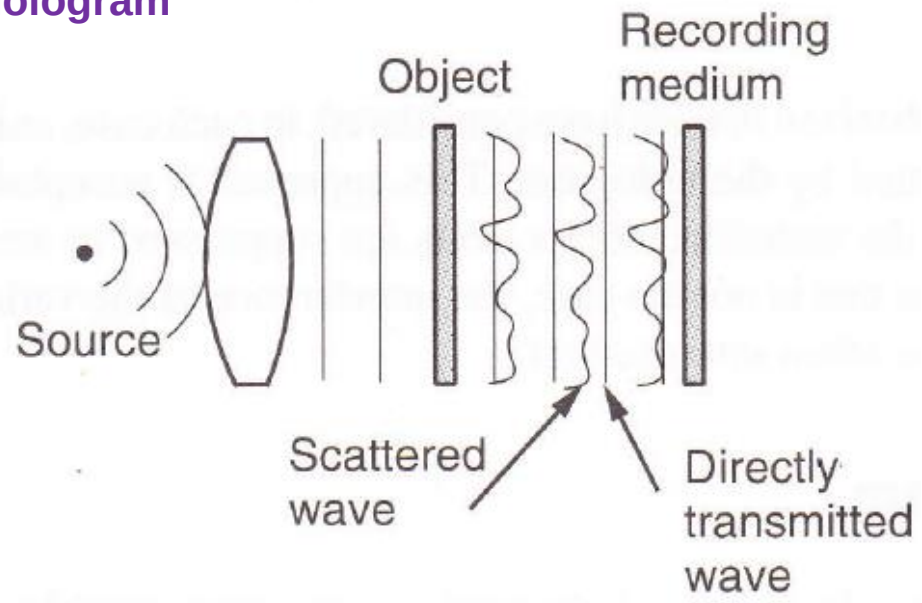

Reconstruction
beam
A
Hologram
y_o
x_o
Virtual
image
z_o

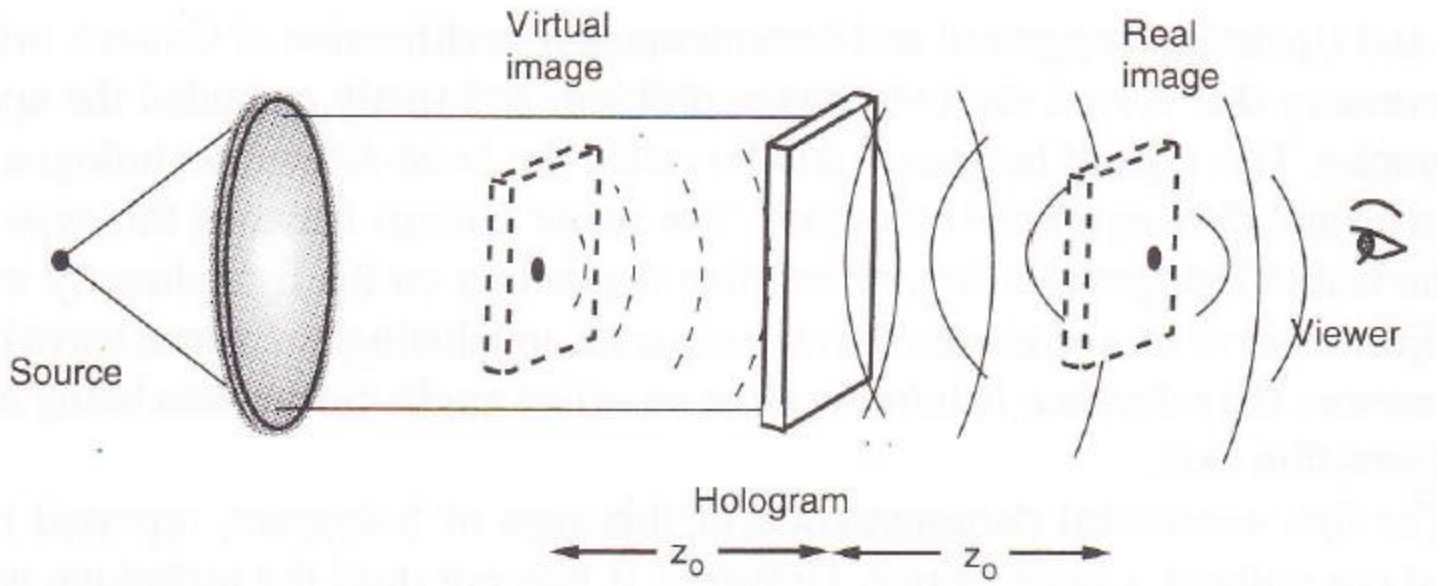
(b)


Reconstruction
beam
A^*
Real
image
z_o
Hologram

(c)

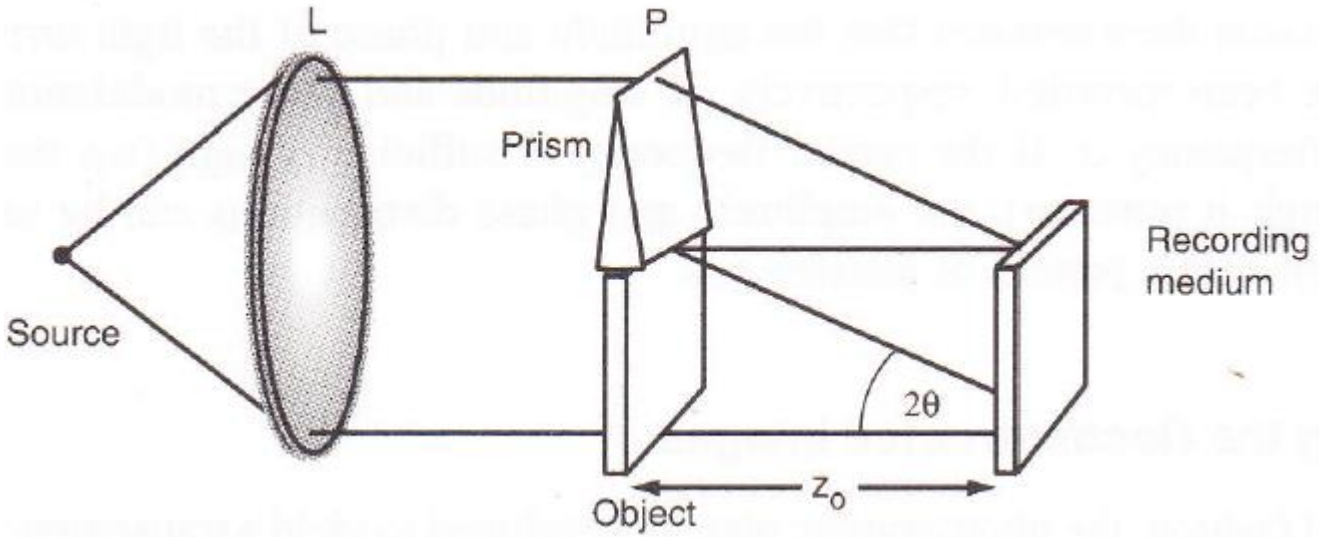
Recording a Gabor hologram



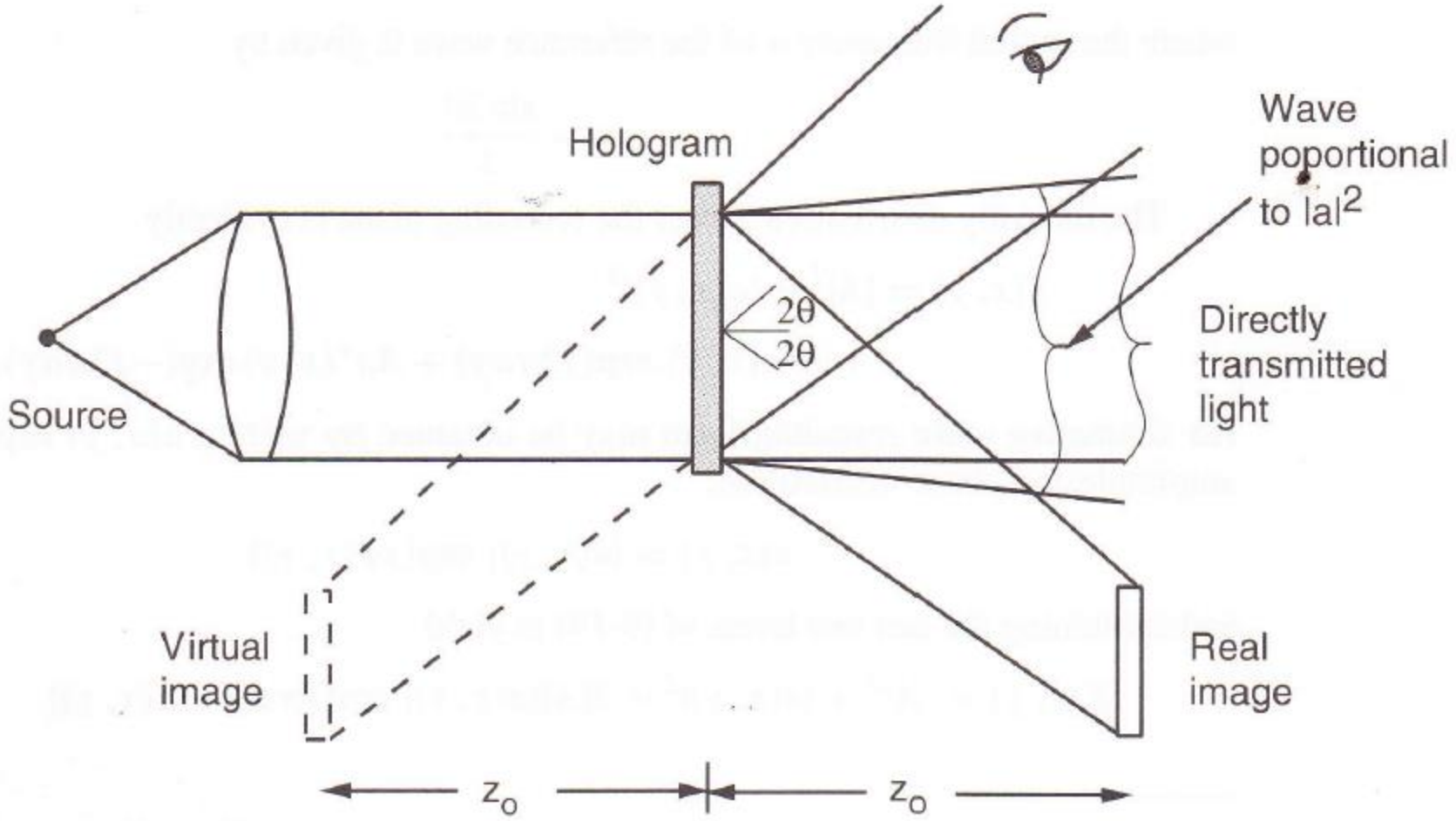


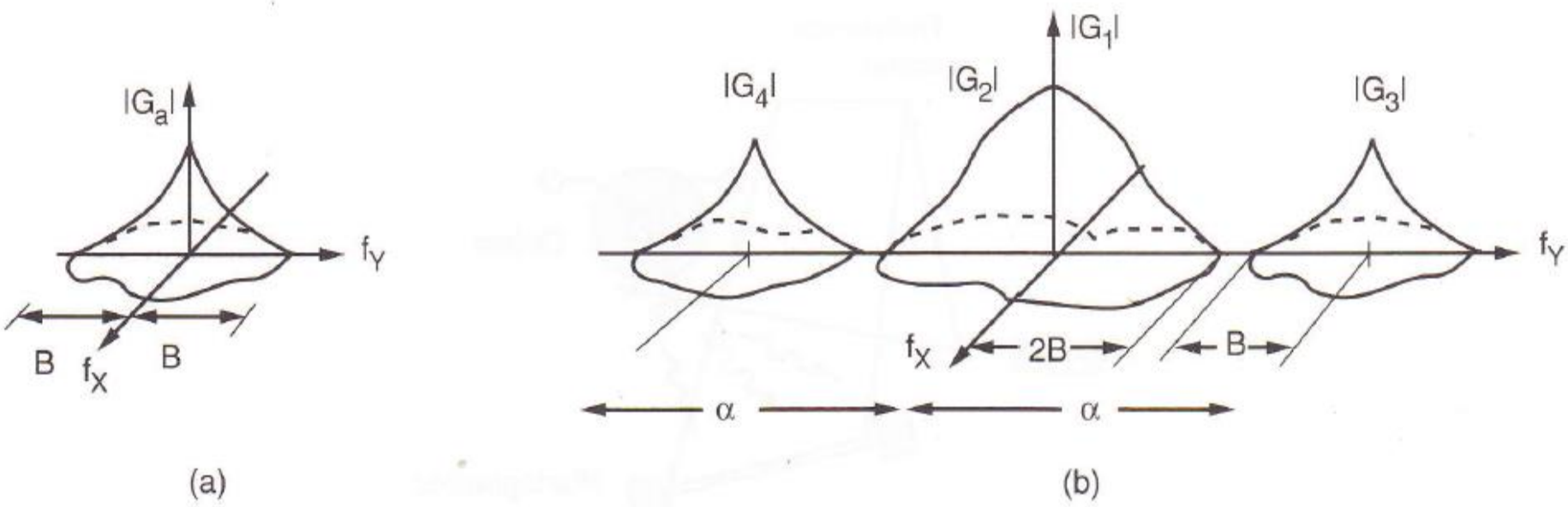
Formation of twin images from a Gabor hologram

Recording a Leith-Upatnieks hologram



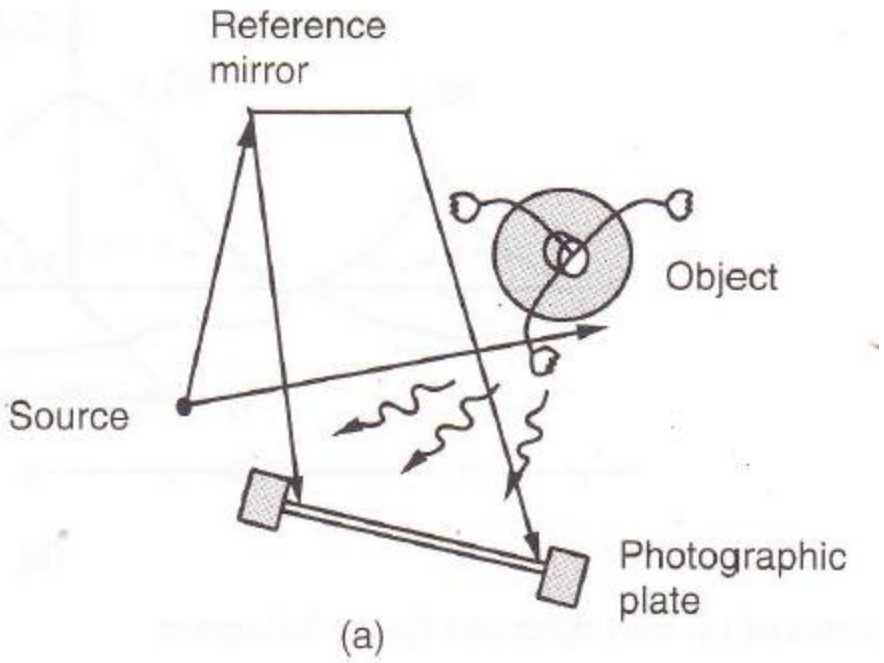
Reconstruction of images from Leith-Upatnieks hologram



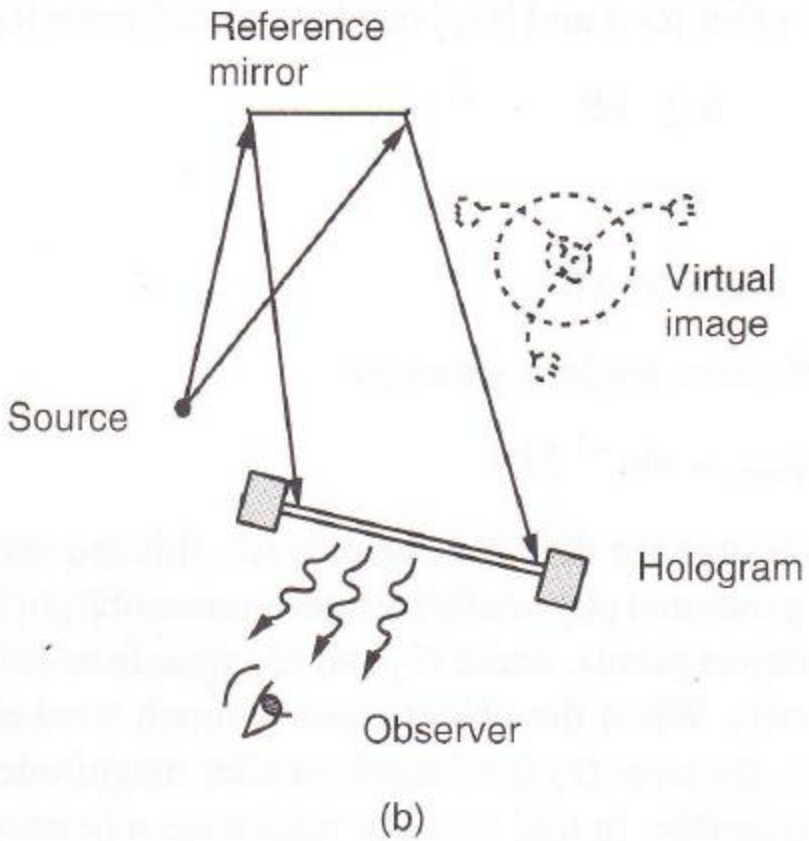


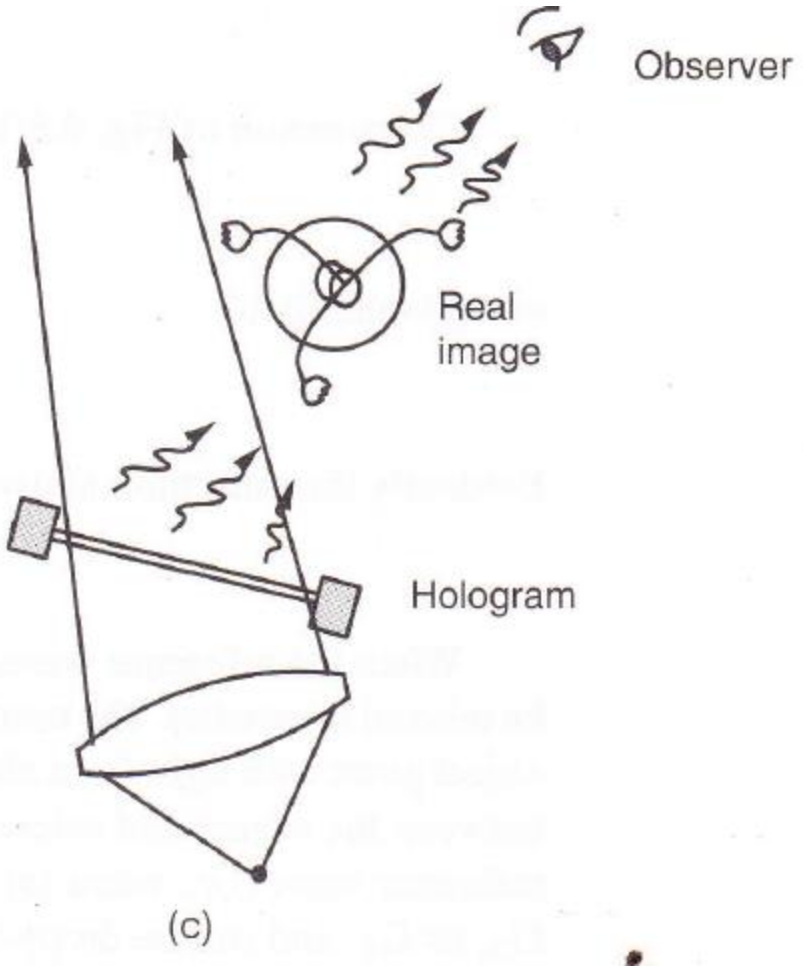
Spectra of (a) the object and (b) the hologram

Holographic imaging of a 3D scene



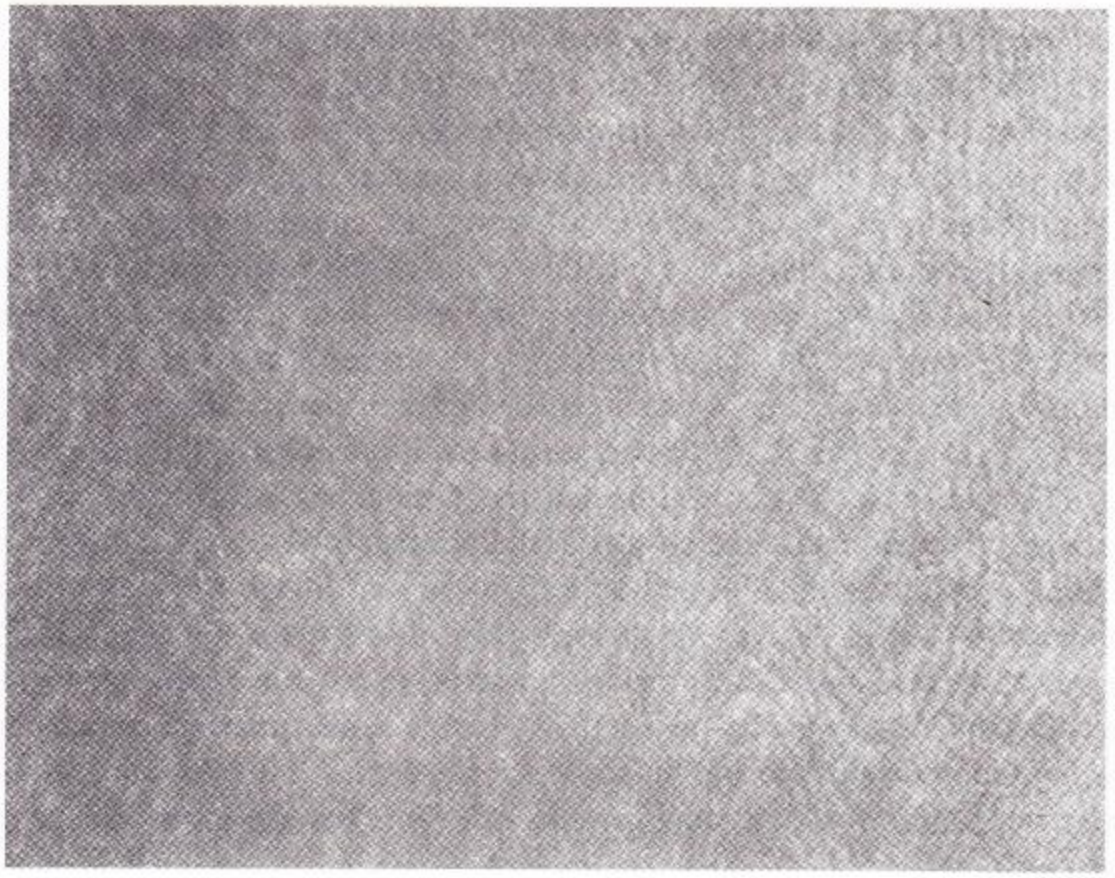
Recording the hologram



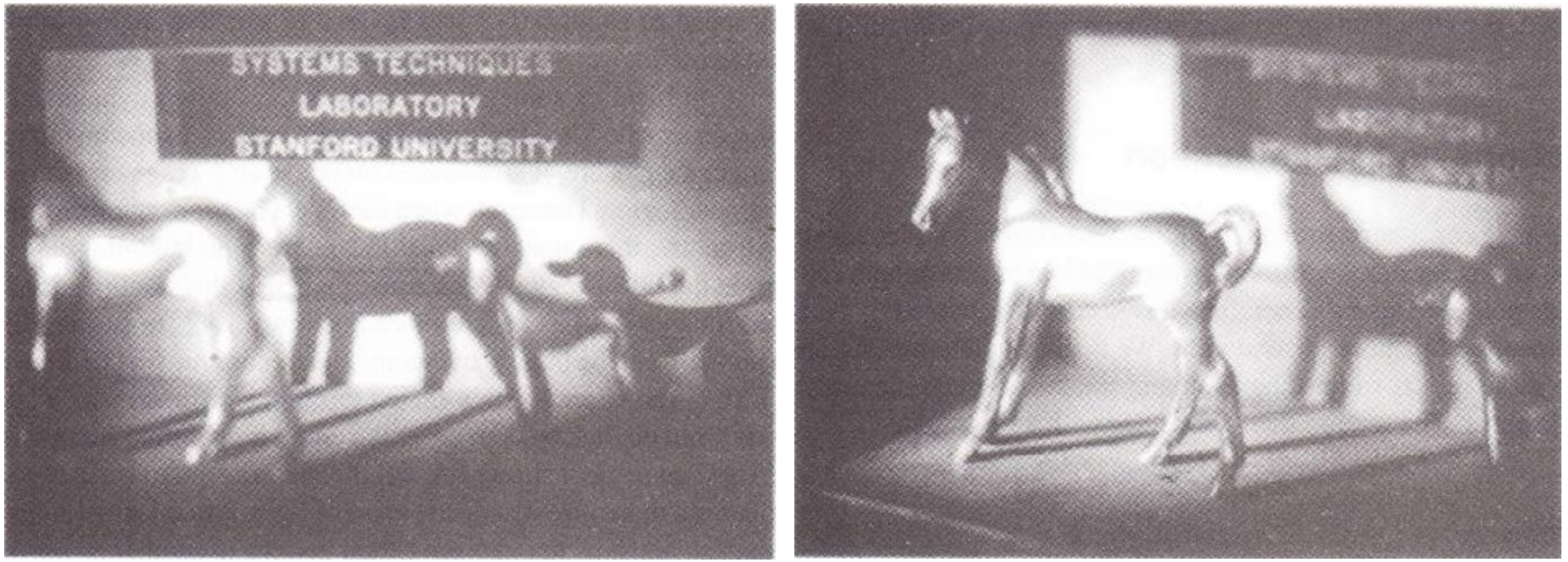


Reconstructing the virtual image

Reconstructing the real image



Photograph of a portion of a hologram of a diffuse 3D scene



Photographs showing 3D character of virtual image reconstructed from a hologram