Holography

by

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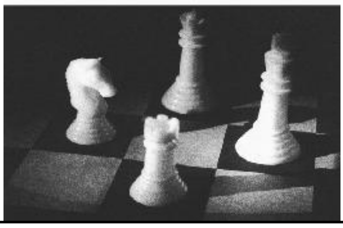
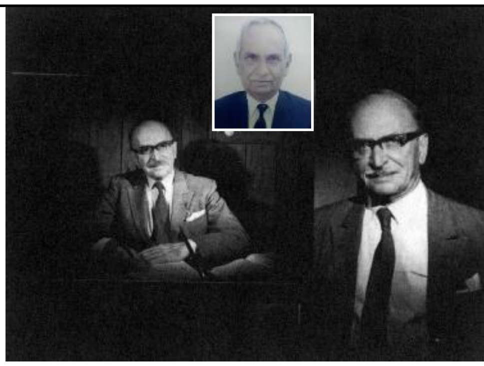
My homage to my GURUS
Prof. T. P. Pandya
Prof. L.M. Bali
Prof. U. Malviya
Prof. P.Jha
who introduced me to
Lasers, Holography, Non-linear Optics





Professor Gabor with his holographic portrait: this hologram was produced by R. Rinehart at the McDonnell Douglas Electronics company in 1971, using a pulsed ruby laser. *In between is Prof. T.P. Pandya, PhD student of Prof. Gabor, Nobel Laureate for Holograhy*

Photograph

•2d recording of a 3d scene

•Only intensity distribution recorded

•In a developed negative the optical density of each point is a function of optical energy received there (light sensitive chemical reaction reduces AgBr to Ag.

•The photosensitive medium is sensitive only to the intensity variations and hence while recording a photograph the phase distribution which prevailed at the plane of the photo is lost.

•So, the 3d character (parallax) of the object scene is lost.

To record the third dimension properly

one needs to record depth,

it implies recording of phase,

but the photo plate records only intensity,

so convert the phase information to amplitude information,

interference phenomenon gives the solution.

- Concept of holography, also known as Wavefront Reconstruction – Dennis Gabor – 1948

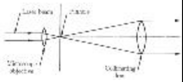
- Difficulty – virtual and real images could not be separated (in-line recording)

- Handicap – high intensity coherent source of light not available

- holos – whole
- graphein – to write
- gram – message
- Hologram is recorded on a light sensitive medium (photographic plate)

- It is a recording of interference patterns formed between two beams of coherent light coming from the same laser.

- The laser beam is first divided into two beams by a beam splitter



- Next it is broadened
- One beam goes directly to the plate
- Other beam is directed onto the 3d object under investigation / observation

- Each point of the object reflects the part of the beam reaching it toward the plate

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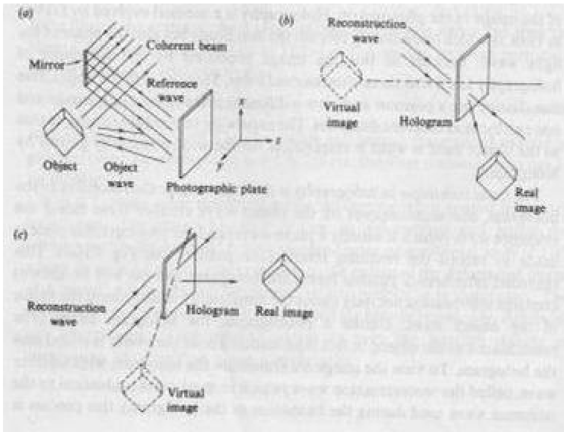
- As each point scatters the light, it acts as a point source of spherical waves.

- At the photo plate the innumerable spherical waves from the object combine with the light wave of the first beam.

- Both beams are coherent – from same laser- can produce stable interference pattern.



- Interference fringes are formed on photo plate and recorded (AgBr reduces to metallic silver).

- Fringes are a series of zone plates – like rings but these rings are also superimposed making incredibly complex pattern of lines and swirls.

- Developed negative is the **HOLOGRAM.**

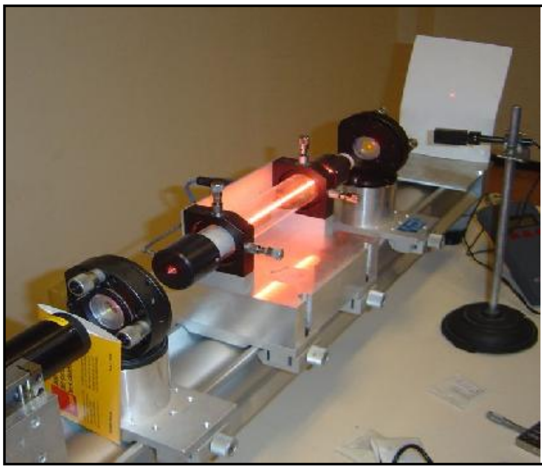
- Seems to bear no direct relation with an image of original object.

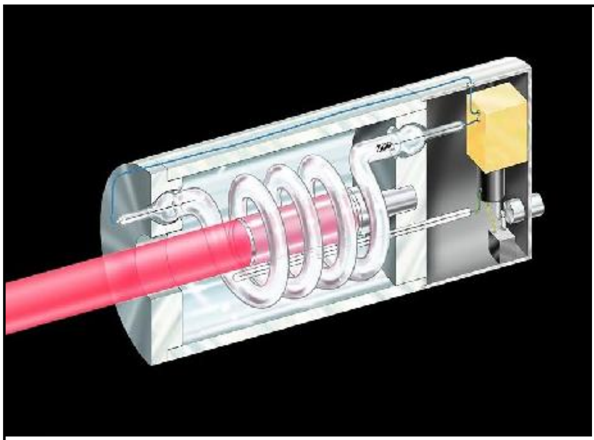
- But both the intensity and phase information is recorded

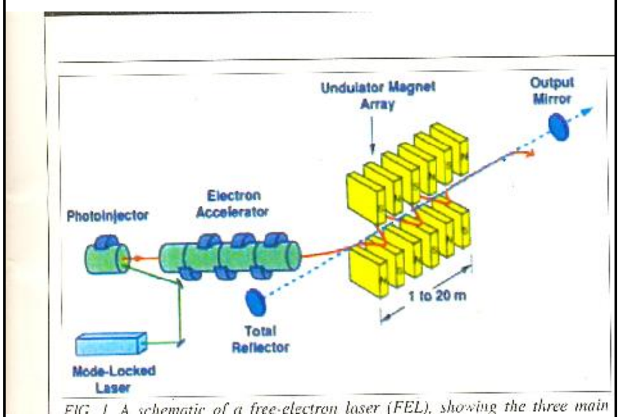
- Diffracted rays form two images
  - Virtual
  - Real

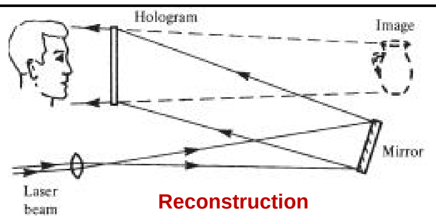
- Real image can be photographed without the aid of lens by placing just a light sensitive medium at the position.

- **Wavefronts can be reconstructed**
- **a 3d image of great vividness and verisimilitude can be reconstituted.**
- **For reconstruction hologram is illuminated by a parallel beam of light from the laser.**
- **Most of the light passes straight through**
- **Light is diffracted at a fairly wide angle from the complex of fine fringes which act as an elaborate diffraction grating.**

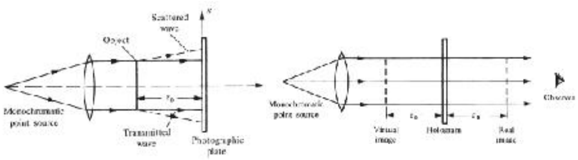




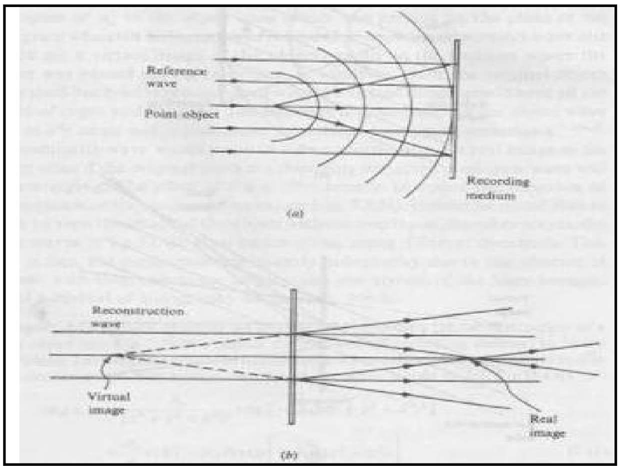




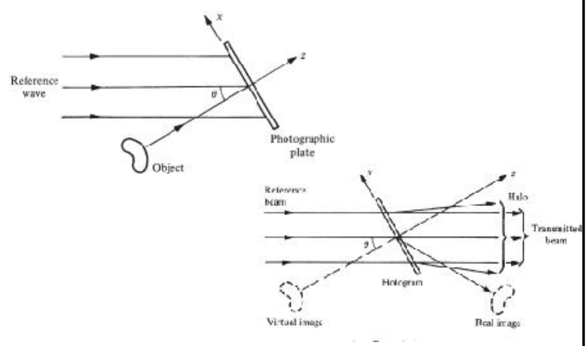
Reconstruction



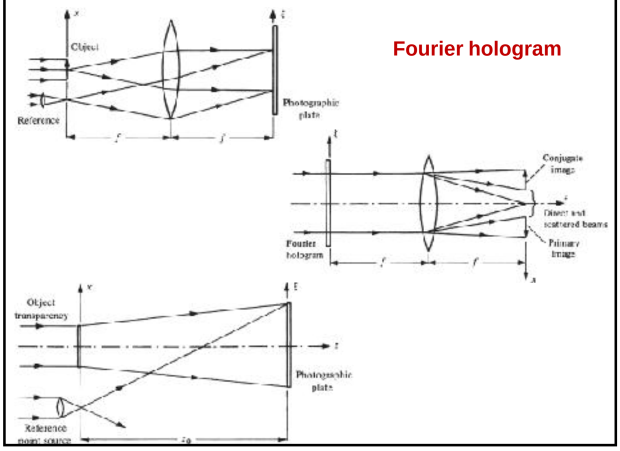
On-axis hologram

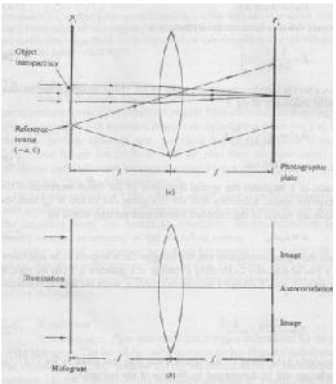


Off-axis hologram



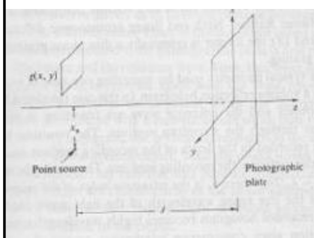
Fourier hologram

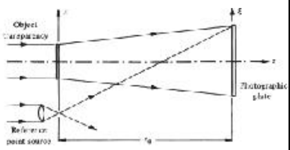


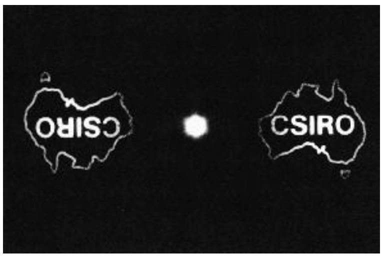


Lensless Fourier holograms

A hologram with the same properties as a Fourier hologram can be produced, without a lens. In this recording arrangement, the effect of the spherical phase factor associated with the near-field (or Fresnel) diffraction pattern of the object transparency is eliminated by using a spherical reference wave with the same average curvature.



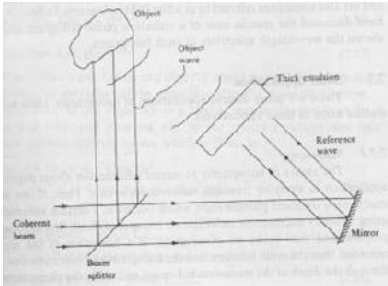




Reflection holograms

- It is also possible to record a hologram with the object beam and the reference beam incident on the photographic emulsion from opposite sides.
- The interference fringes then form a series of planes within the emulsion layer, at a small angle to its surface and about half a wavelength apart.
- Such holograms, when illuminated with a source of white light, reflect a sufficiently narrow band of wavelengths to reconstruct an image of acceptable quality.

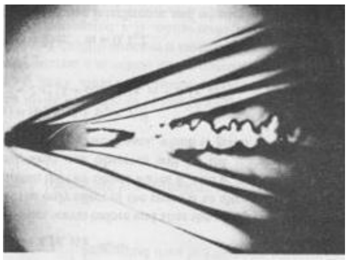
Recording of Reflection holograms



Conventional vs. Holographic Photography

•Brings into focus every part of the scene in the field of lens.
•lacks perception of depth/parallax: not a real-life scene
Hologram – whole message
•In a developed photo:
optical density of the emulsion at each point
= f (op. density received there which reduces silver to its metallic form).
•Phase relationship of waves arriving from different directions and distances is not recorded : not life-like.

- To record phase relationship, phase information should be converted to amp. Information.
- One to one



For a simple holographic system, the He–Ne laser is the usual choice.

It is inexpensive and operates on a single spectral line at 633 nm which is well matched to the peak sensitivity of many photographic emulsions. In addition, it does not require water cooling and has a long life.

The visibility of the interference fringes forming the hologram is maximum when the electric vectors of the object and reference beams are parallel. It is always so if the two beams have s-linear polarization.

Lasers used for holography

• Ar	514	1 W
• He–Cd	442	25 mW
• He–Ne	633	2–50 mW
• Kr	647	500 mW
• Diode	670–650	5 mW
• Diode–YAG	532	100 mW
• Dye tunable		200 mW
• Ruby pulsed	694	1–10 J

• Argon-ion (Ar) lasers are more expensive and complex, but give much higher outputs in the green (514 nm) and blue (488 nm) regions of the spectrum. The Ar laser normally has a multiline output but can be made to operate at a single wavelength by replacing the reflecting end mirror by a prism and mirror assembly.

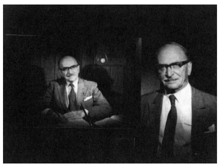
• The krypton-ion (Kr) laser is useful where high output power is required at the red end of the spectrum (647 nm).

•The helium–cadmium (He–Cd) laser provides a stable output at a relatively short wavelength (442 nm) and is useful with recording materials such as photoresists.

•Diode lasers can be used as a source of red light, and are now available with output wavelengths that are fairly well matched to the sensitivity of commercial photographic materials.

•Dye lasers are relatively expensive and complex, but have the advantage that they can be operated over a wide range of wavelengths by switching dyes.

•Additionly the output can be tuned over a range of wavelengths (50–80 nm) by incorporating a wavelength selector, such as a diffraction grating in the laser cavity.



A Q-switched ruby laser can also be used to record holograms of living human subjects [Siebert, 1968] .

However, to avoid eye damage, instead of illuminating the subject directly, the expanded laser beam should be allowed to fall on a large diffuser which constitutes an extended source illuminating the subject.

A studio setup for making holographic portraits has been described by Bjelkhagen [1992].

Laser safety

Since the beam from a laser is focused by the lens of the eye to a very small spot on the retina, direct exposure to low power lasers can cause eye damage.

With pulsed lasers, even stray reflections can be dangerous.

It is essential to take all due precautions to avoid accidental exposure and, where required, to use appropriate eye protection

Copying holograms

It is often necessary to make copies from a single original hologram.

One way is to illuminate the hologram with the conjugate of the reference wave used to make it. The wave reconstructed by the hologram can then be used with another reference wave to record a second-generation hologram. This technique has the advantage of great flexibility. It is possible to produce a copy that reconstructs an orthoscopic real image as well as copies with improved diffraction efficiency. It is also possible to produce a number of reflection holograms from a transmission hologram of the object.

'Contact printing'

A simpler way to produce many identical copies of a hologram is to 'contact print' the original on to another photosensitive material [Harris, Sherman & Billings, 1966].

Since what is recorded on the copy material is actually the interference pattern formed by the light diffracted by the hologram and the light transmitted by it, the coherence of the illumination must be adequate to produce interference fringes of high visibility.

Computer-generated holograms can produce wavefronts with any prescribed amplitude and phase distribution and have, therefore, found many applications.

Procedures for making such holograms for lecture demonstrations, using a desktop computer, have been described in several publications [McGregor, 1992].

The availability of high-resolution laser printers has eliminated the need for photographic reduction, and 7575 element, detour-phase holograms can be produced directly on overhead transparency film [Walker, 1999].

Optical testing

One of the main applications of computer-generated holograms is in optical testing, where they are used in interferometric tests of aspheric surfaces. In this application, a computer-generated hologram replaces an expensive null lens used to cancel the aberrations of the test wavefront [Wyant & Bennett, 1972].

If, as shown in the test surface is imaged on the hologram, the superposition of the actual interference pattern and the hologram produces a moiré pattern showing the deviation of the test wavefront from the ideal computed wavefront.

Holographic diffraction gratings

High quality diffraction gratings can be produced by recording an interference pattern in a layer of photoresist coated on an optically worked substrate [Schmahl & Rudolph, 1976; Hutley, 1982]. Holographic gratings, as they are commonly called, are free from periodic and random errors and exhibit very low levels of scattered light.

Holographic optical elements

A hologram can be used to transform an optical wavefront in the same manner as a lens.
In addition, computer-generated holograms can produce a wavefront having any arbitrary shape.
As a result, holographic optical elements (HOEs) can perform unique functions and have been used in several specialized applications.
A major advantage of HOEs over conventional optical elements is that their function is independent of substrate geometry.
In addition, since they can be produced on thin substrates, they are quite light, even for large apertures.

Another advantage is that several holograms can be recorded in the same layer, so that spatially overlapping elements are possible. Finally, HOEs provide the possibility of correcting system aberrations in a single element, so that separate corrector elements are not required.

The recording material for a HOE must have high resolution, good stability, high diffraction efficiency and low scattering. Photoresists and dichromated gelatin are, at present, the most widely used materials. Photopolymers are an attractive alternative.

Holographic optical elements are lighter and can be fitted into the limited space available.

Beam shaping

Holographic optical elements are now used widely with laser diodes to correct the divergence and astigmatism of the beam [Hatakoshi & Goto, 1985].

Two HOEs can also be used to generate a uniform circular or rectangular beam [Han, Ishii & Murata, 1983].

Another interesting application has been to generate beams with an amplitude profile described by a Bessel function [Vasara, Turunen & Friberg, 1989]. **Such a beam has the property that its intensity profile does not change as it propagates,making it very useful for precision alignment.**

Yet another application has been in optical heads for compact-disc players [Lee, 1989].

Interconnection networks
Integrated circuits in a computer are traditionally connected by metallic wires. Optical interconnections using holographic optical elements minimize propagation delays; in addition, they reduce space requirements, since several signals can propagate through the same network without mutual interference.

Holographic memories
The maximum useful storage density with conventional techniques is set by the fact that dust or scratches can result in total loss of significant parts of the information. With holograms, surface damage only results in a drop in the overall signal-to-noise ratio, making much higher storage densities possible.

Holographic neural networks
Holographic neural networks are attractive because they offer large storage capacity as well as parallel access and processing capabilities.

Holography makes it possible to store a wavefront and reconstruct it at a later time. As a result, interferometric techniques can be used to compare two wavefronts which were originally separated in time or space.

In addition, since a hologram reconstructs the shape of an object with a rough surface faithfully, down to its smallest details, large scale changes in the shape of almost any object can be measured with interferometric precision *[Brooks,Heflinger&Wuerker, 1965; Burch, 1965; Collier,Doherty & Pennington, 1965; Haines & Hildebrand, 1965; Stetson & Powell, 1965].*

Holographic interferometry is now used extensively in nondestructive testing, aerodynamics, heat transfer and plasma diagnostics *[Vest, 1979; Rastogi, 1994]* as well as in studies of the behavior of anatomical structures and prostheses under stress *[Greguss, 1975; von Bally, 1979; Podbielska, 1991, 1992].*

OPTICAL FIBER

1838- Telegraph-wire cables

Later - radio waves - e. m. radiation for transmission

Sinusoidal carrier wave + information signal : through atmosphere ⟶ information extracted

Greater freq. of carrier ⟶ Greater information sent

Radio	300KHz - 30 MHz	
TV	30 - 3000MHz	
Satellite links	90 GHz	

Optical 10^{15} Hz — tremendous data can be sent

Laser carrier :: 10 million TV channels theoretically

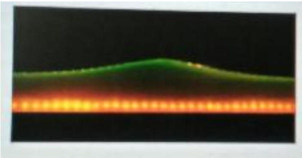
Era of Optical Communication came

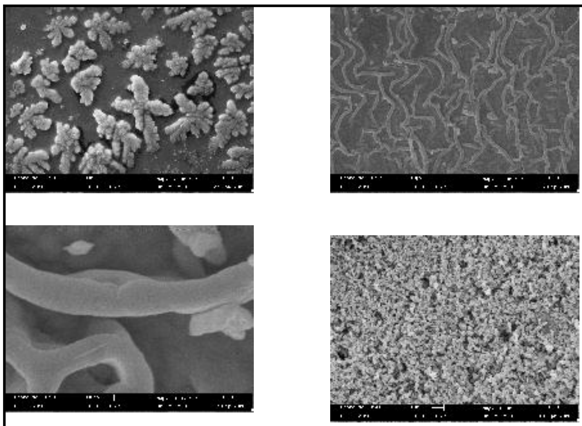
Fog, dust are hinderance

A waveguide needed

Optical Fiber Came

Advantages: silica, cheap, abundant, light weight, no EMI, no crosstalk, no short circuiting, useful in electrically noisy atmosphere, no tapping, no monitoring, large bandwidth





Thank you