INDUSTRIAL FIBER OPTICS

Sandbox Holography Kit

Reference manual and experiment guide

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45-733A Revision C

Printed in the United States of America

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INTRODUCTION

This manual provides information about Industrial Fiber Optics 45-633 A Sandbox Holography Kit. This new version incorporates technology and updates that offer innovative content for today's young experimenters and scientists of the future.

This manual contains experiments developed by active teachers and thoroughly tested in the classroom.

Industrial Fiber Optics makes every effort to incorporate state-of-the-art technology, highest quality and dependability in its products. We constantly explore new ideas and products to best serve the rapidly expanding needs of industry and education. We encourage comments that you may have about our products, and we welcome the opportunity to discuss new ideas that may better serve your needs. For more information about our company and products, refer to ***http//www.i-fiberoptics.com*** *on the worldwide web*

Thank you for selecting this Industrial Fiber Optics product. We hope it meets your expectations and provides many hours of productive activity.

Sincerely,

The Industrial Fiber Optics Team

SAFETY NOTES

Lasers create a very special type of light that guarantees exciting laboratory experiments and visual demonstrations for inquiring young minds.

Industrial Fiber Optics (IFO) helium-neon lasers emit a beam of visible orange-red light. They do not emit invisible, exotic, or otherwise harmful radiation.

IFO low power lasers have a light output of only a few thousandths of a watt and should not be confused with the powerful commercial lasers used for burning, cutting and drilling.

Even so, the laser beam must be treated with caution and common sense because it is intense and concentrated. The greatest potential for harm with IFO lasers is to the eyes. No one should look directly into the laser beam or stare at its bright reflections, just as no one should stare at the sun.

The United States Department of Health, Education and Welfare regulates the manufacture of lasers to ensure users are not endangered. The federal government classifies lasers according to their power levels and specifies appropriate safety features for each level. Demonstration lasers fall into Class II and can be identified by a yellow CAUTION label that contains the warning Do not Stare into Beam, along with a universal laser warning symbol. Class II lasers have a maximum power of 1/1000th of a watt, a power judged to be eye-safe, except possibly in case of deliberate, long term direct staring into the beam. Safety features include a pilot lamp that glows when the electrical power is ON and a mechanical beam-stop that blocks the beam when power is on. In addition, IFO observes safety directives issued by the European Standards Committee for optical and electric safety, including directives 89/336/EEC and 92/59/EEC for lasers and EN 71-1 for optics kits.

Laser Safety

1. Instruct students not to look into the laser or stare at bright reflections of the beam.
2. Remove all reflective objects from the work area, including rings, watches, metal bands and tools. Beam reflections can be nearly as intense as the original beam.
3. Block the beam beyond the farthest point where it will be useful. Use a dull, non-reflective object, such as a piece of wood.
4. If the beam must travel a long distance, keep it directed close to the ground or overhead so it does not cross walkways at eye level.
5. Never use magnifiers such as binoculars or telescopes to look at the beam as it travels or when it strikes a surface.
6. Never allow unauthorized people to handle lasers; store them in a safe place away from unauthorized users.
7. Lasers are not toys; use them only for educational purposes.
8. Never point a laser at anyone, no matter how far away.
9. Make sure the laser is always secured on a solid foundation. Keep power cords and adapters away from areas where they can be accidentally disturbed.
10. Helium-neon lasers employ high voltages. The power supply retains potentially harmful voltage for periods after the input power has ceased. Never open the housing and expose anyone to these voltages.
11. Keep these safety regulations near the laser, and read and refer to them in case of safety questions.
12. If you have any safety questions, please contact Industrial Fiber Optics at (480) 804-1227 or info@i-fiberoptics.com

General Safety

1. Since optics kits contain glass pieces, it is important to remember that they can present a cutting hazard. Please handle them carefully and make sure that you do not contact any edges that might cut you.
2. To fully utilize this manual and its safety warnings, we recommend that the manual be kept close to the optics lab.

Electrical Safety

1. Never disassemble or try to adjust the laser's internal components. Electric shock could result.
2. If the laser is equipped with a UL-approved line cord and 3-prong grounded plug, ALWAYS PLUG THE LASER INTO A GROUNDED OUTLET.
3. For further information about laser safety and the federal regulations involved, contact the Compliance Officer at the Bureau of Radiological Health.
4. Also contact the Public Health Service, Food & Drug Administration, Rockville, MD 20857. Telephone: [301] 443-4874. Ask for Regulation Publication HHS PUB FDA 80-80356.

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BACKGROUND INFORMATION

Holography was one of the most important scientific discoveries of the 20th century. Dennis Gabor, a Hungarian physicist, developed holography theory in 1947. He was investigating methods for improving the performance of an electron microscope, and his holographic observations came as an unexpected bonus. The invention and development of the laser in the early 1960s enabled many scientific and industrial applications for his discovery, and in 1971, he was awarded the Nobel Prize in Physics for it. Dr. Gabor coined the word 'hologram', derived from the Greek "holos" meaning whole or complete and "gram" meaning message.

Holography is a visual recording and playback process that captures a three-dimensional scene on a two- dimensional medium, and then recreates a true three-dimensional image of it. The recreated image displays all of the parallax and depth of field of the original scene. Parallax is the ability to look around objects and see the other objects behind them, and the apparent displacement, or difference in position, of an object when we view it from different angles. Depth of field is the ability to use depth perception to direct your attention through a scene from front to back, observing the locations of objects that are nearer or farther away.

Another fascinating property of a hologram is that even a tiny portion of it, any portion, contains all the information needed to recreate the entire image. The image will appear to be displayed from the point of view of the fragment's position in relation to the rest of the hologram.

A hologram captures a three-dimensional image of a scene or object by recording an interference pattern formed by the interaction of two wavefronts striking the holographic film, as shown in Figure 1a. One of the wavefronts (the Object Wavefront) is reflected off the object or scene being captured. The other is a planar (two dimensional) "reference" wavefront. The superposition of these two wavefronts at the surface of the film creates a pattern of interference fringes that are recorded by the film. Unlike the image recorded by typical film cameras, this interference pattern contains not only the intensity of the light striking the medium at a given point, but also the phase relationship between the two wavefronts. When illuminated by an appropriate light source, as shown in Figure 1b, the hologram acts as a complex diffraction grating, faithfully reproducing a three-dimensional image of the original scene or object.

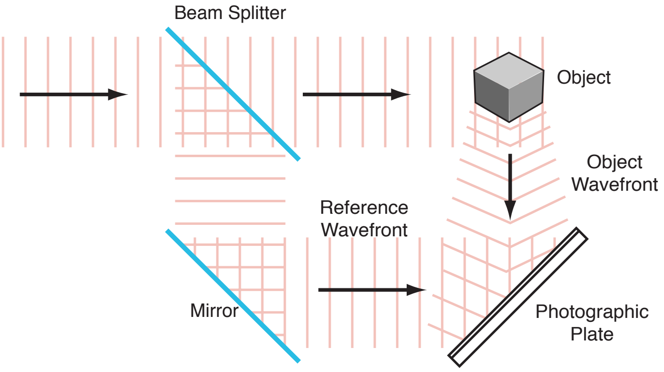


Figure 1a. Recording a hologram.

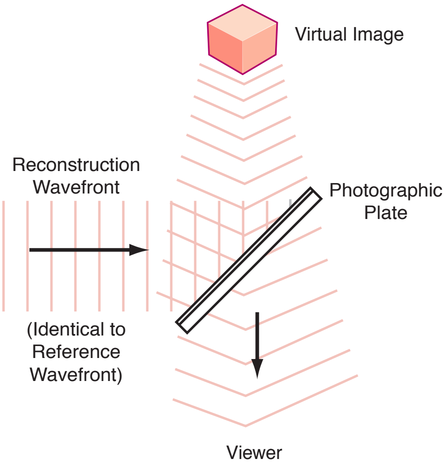


Figure 1b. Reproducing the image.

There are many different types of holograms, and they have many types of applications. For example, holography can be used in medical imaging and for data storage. Since holograms are very difficult to counterfeit, they can be used for security purposes to confirm the authenticity of products and documents. Holographic techniques also can be used to create holographic and diffractive optical elements that have superior qualities as compared to refractive optical components.

This kit will make the two most common types of holograms, reflection holograms and transmission holograms. A reflection hologram acts as a mirror — light reflecting off the hologram reconstructs a three-dimensional image. A transmission hologram acts like a pane of window glass. When properly illuminated, the image is recreated on the opposite side of the hologram. The image is viewed as if being seen through a window.

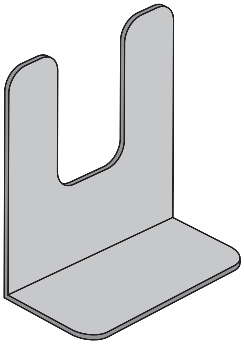
EQUIPMENT INCLUDED IN THIS KIT

Industrial Fiber Optics' Sandbox Holography Kit (45-633A) contains the basic optical components to perform all of the holographic setups in this manual. It also contains high resolution holographic film and a developing kit for it. The Sandbox Holography Kit features magnetic holders called "Maggie" Mounts". These mounts permit fast experimental set-ups that are readily adjusted and aligned, yet retain their positions once in place. The catalog number of each item is listed in the table below. To help identify lenses and other optical components in the kit, approximate dimensions and focal lengths are provided. To order replacement parts, see our website **http//www.i-fiberoptics.com**

U-Shaped Carrier

This is a carrier with two vertical posts about 3 cm apart. Its steel surface allows other components to be attached magnetically.

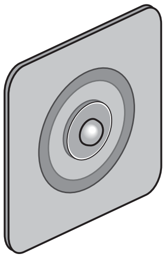
No. 45-649A
Qty. 5



Diverging Lens Plate

A lens mounted on a 6 cm steel square. When magnetic tape is attached to the steel plate, it can be mounted to a U-Shaped Carrier. Focal length is –10 mm.

No. 45-631A
Qty. 2



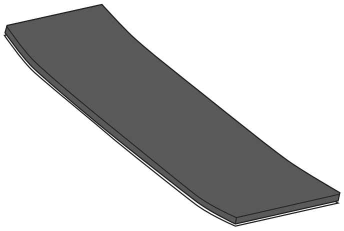
Holography Manual

No. 45-733A Qty. 1

Magnetic Strips

These 15 cm long strips have an adhesive backing. They can be cut with scissors and attached to lens plates, mirrors and the beam splitter so they can be held magnetically to the U-Shaped Carriers.

No. 45-660 Qty. 2



1/4"-20 Screw, 6mm long

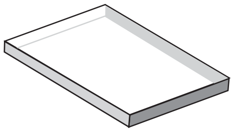
Used to plug tripod mount hole in bottom of laser.

No. 45-114
Qty. 1

Beam Splitter

This 38 x 25 x 6 mm rectangular piece of glass divides a laser beam into two components.

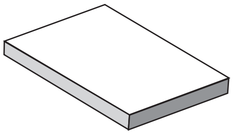
No. 45-335
Qty. 1



Front Surface Mirror

Two 38 x 25 mm mirrors with an aluminized first surface coating.

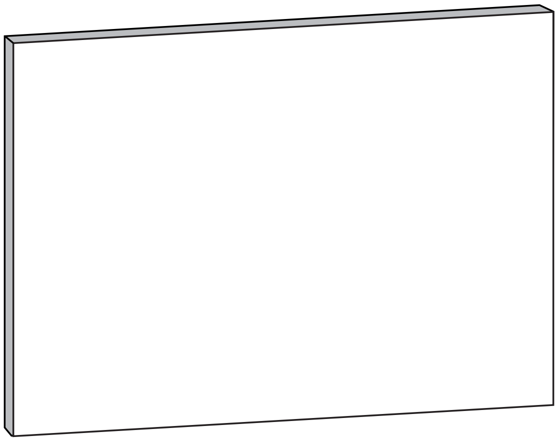
No. 45-646 Qty. 2



Front Surface Mirror

A larger 110 x 80 mm first surface mirror

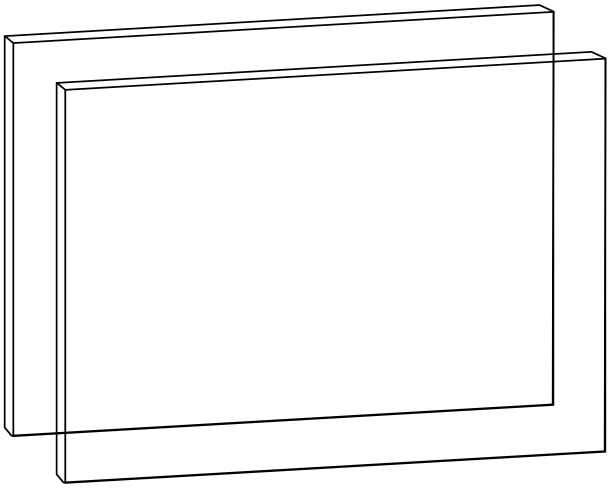
No. 45-637 Qty. 1



Glass Plates (110x80mm)

These 110 x 80 mm glass plates are used with the Spring Steel Clamps to form a film holder to securely mount the holographic film.

No. 45-638
Qty. 2



Beam Test and Shutter Card

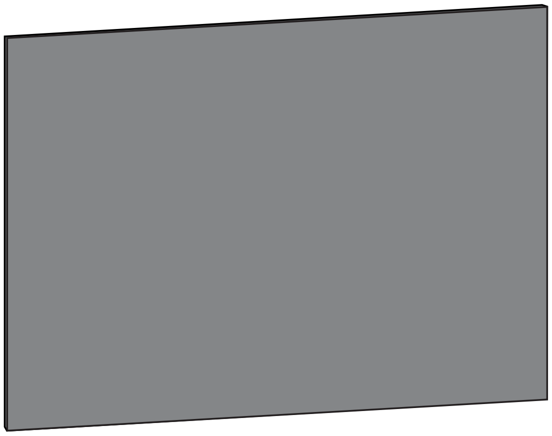
The dark side of this card is used to block the laser beam just before an exposure. The light side can be used to estimate a beam's brightness.

No. 45-326 Qty. 2

Green Filter

This 110 x 80 mm sheet of dark green gel filter can be used to fashion a safelight.

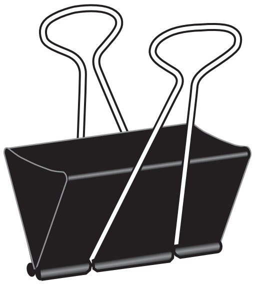
No. 45-359 Qty. 1



Binder Clips

Used to clamp film holder together.

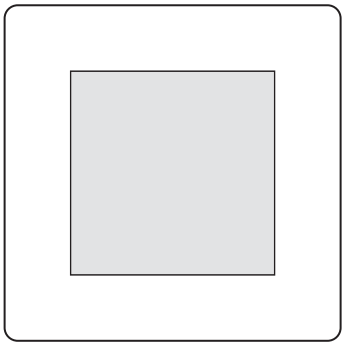
No. 45-110 Qty. 2



Transmission Hologram

This 50 x 70 mm holographic film has been exposed and developed. When illuminated by laser light and viewed from the proper angle, a three-dimensional view results.

No. 45-624 Qty. 1



Coated Convex Mirror

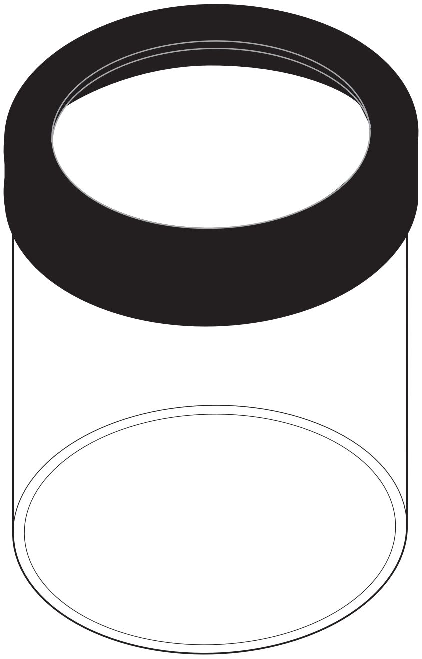
This convex mirror is used when making 360° cylindrical holograms.

No. 45-608 Qty. 1

Clear Plastic Jar with Lid

This jar is used as a film holder while making 360° cylindrical holograms.

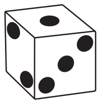
No. 45-307 Qty. 1



Subject Cube (Playing Die)

The Die's six different sides make it an excellent subject of a 360° cylindrical hologram.

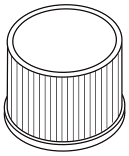
No. 45-801 Qty. 1



Plastic Cap

Used as a stage for mounting Playing Die.

No. 45-309 Qty. 1

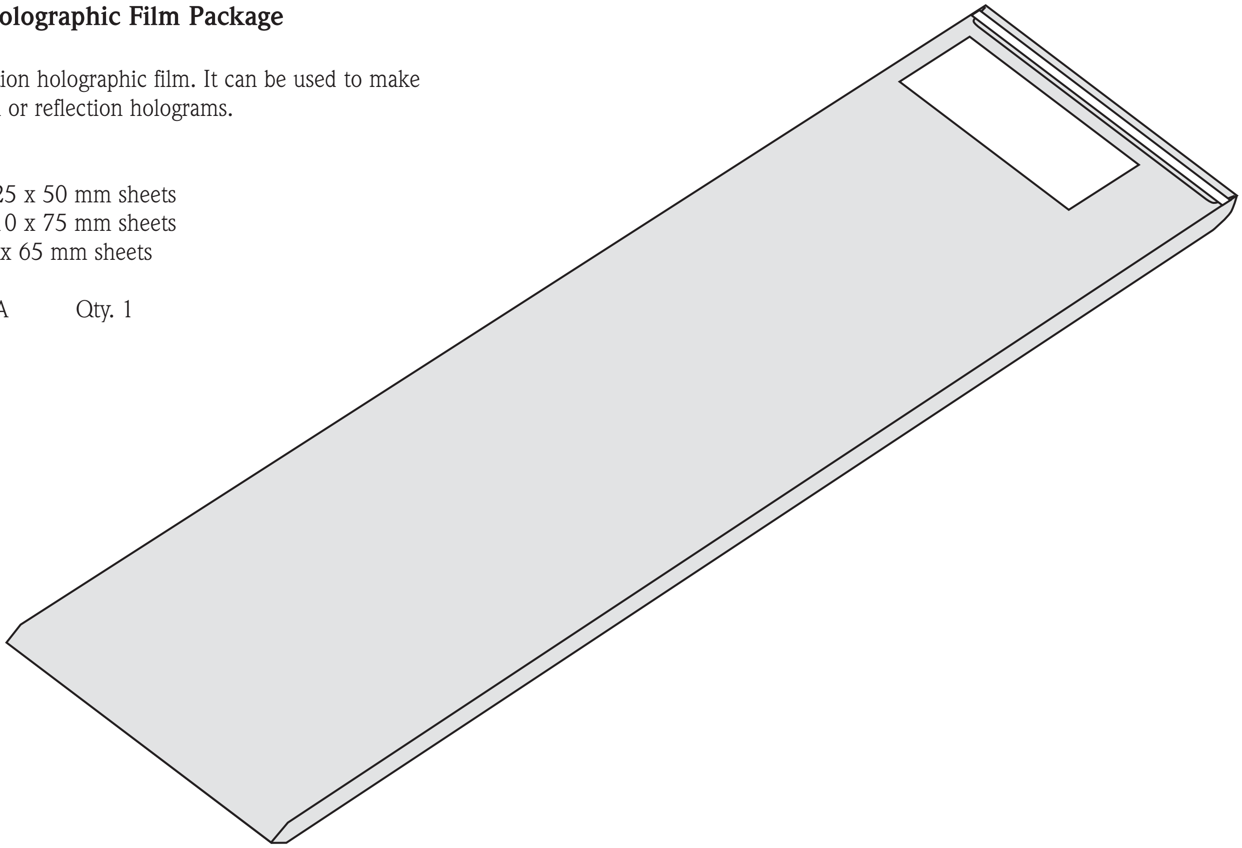


PFG-01 Holographic Film Package

High resolution holographic film. It can be used to make transmission or reflection holograms.

Contains:
  Two 225 x 50 mm sheets
  Two 110 x 75 mm sheets
  Six 55 x 65 mm sheets

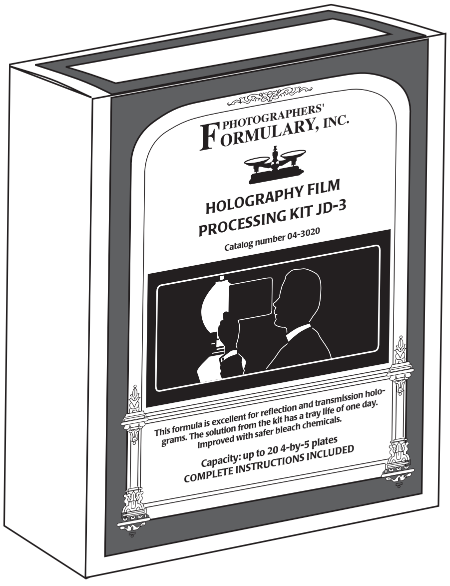
No. 45-636A Qty. 1



Photographer's Formulary JD-3 Holographic Film Processing Kit

Used to develop exposed PFG-01 Holographic Film.

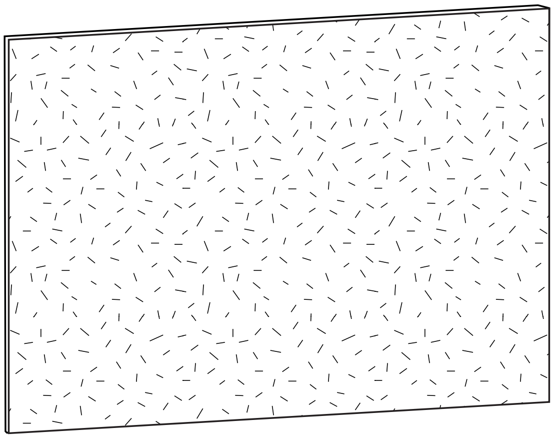
No. 840195 Qty. 1



Plastic Matte Filter

A "frosted" filter used to create a soft lighting effect when illuminating an object.

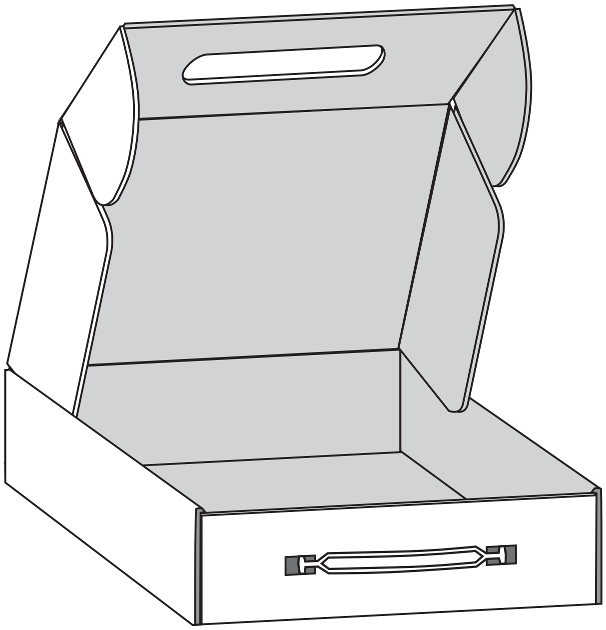
No. 45-305 Qty. 1

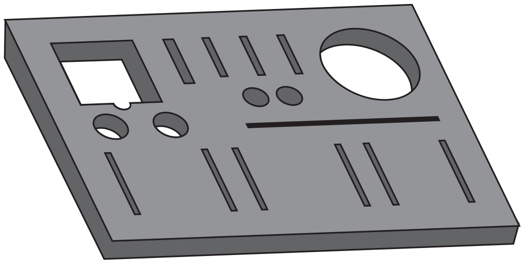


Storage Case and Foam Set

This fitted case holds all of the optical components in the 45-633A kit. The 3-piece foam set fits the storage case to cushion and protect the components.

No. 45-469 Qty. 1





HINTS ON USING ACCESSORIES FOR EXPERIMENTS

Overview

While designing new types of lasers and optical components, our engineers first devised makeshift magnetic mountings for their own convenience. These mounts were effective and saved considerable time in setting up experiments and holding laser optical accessories at correct angles for exploratory work. It was only natural that we make them available to schools and research laboratories as standard catalog items. Engineers dubbed them “Maggie Mounts” and the name stuck.

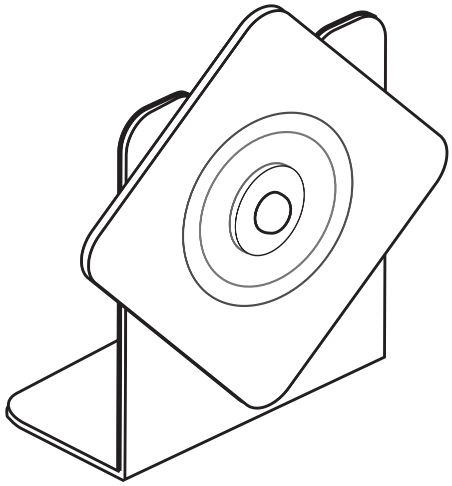
Maggie mounts are chrome steel. In use in this kit, the U Shaped Carriers will be partially buried in sand to provide rigid, stable mounts for the optical components. Although you will probably discover many new ways to use these mountings in your experiments, here are several helpful suggestions for getting started:

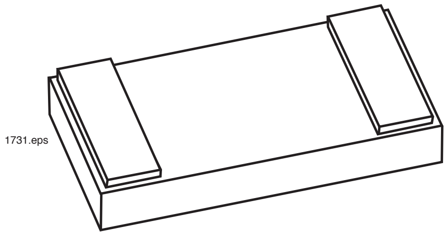
A. Mounting lenses on U-shaped component carriers

The lenses furnished with the Sandbox Holography Kit can be held in place by using the magnetic tape supplied. This tape can be cut with scissors or scored with a knife and then broken along the score line. Remove the paper backing from the tape and press the adhesive side against the desired surface. Be careful not to touch or contaminate the adhesive once the protective paper has been removed. Attach lenses so corners of the mount protrude from the top and sides of the carrier. Corners can be grasped to adjust lens position.

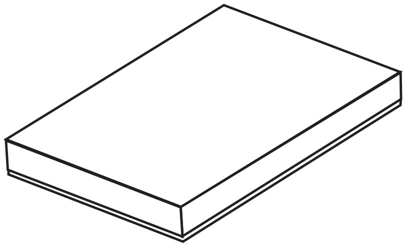
B. Making magnetic mounting for small optics parts

The small optical components furnished with the Sandbox Holography Kit can be held in place by using the adhesive magnetic tape in a similar fashion. Apply the tape to the entire backside of the mirrors. See the section **Mirrors** on page 10 for tips about identifying the front and backside of the mirrors. Apply the tape to just the ends of one side (either side) of the beam splitter as shown.





Beam Splitter



Front surface mirror. Apply tape over entire rear surface.

Figure 2. Using magnetic tape to mount the optics.

BUILDING A SANDBOX

The first step on the path to successfully producing holograms is to build a large, rigid, optical table (sandbox). The sandbox frame and base should be built of 3/4-inch or thicker plywood (exterior dimensions about 100 x 70 centimeters) about 15 centimeters deep. Assemble the sides and bottom of the box using wood glue and 1-inch wood or drywall screws, about 15 centimeters apart. If you have woodworking skills and tools, you may wish to join corners of the sandbox frame with interlocking wood joints of the sort that carpenters and cabinet makers use, but it isn't necessary to build a workable box.

Allow the glue to dry completely. Once a suitable work area has been selected, place two 13- to 15-inch automobile innertubes partially filled with air on a table or countertop. Then place the sandbox atop the innertubes and fill it with playground sand to a depth of about 10 cm.

The sand in the box provides inertial mass to resist movement that might be caused by vibrations of the table or countertop beneath. Partially inflated innertubes under the box further help to dampen these vibrations. This combination provides a stable, movement- and vibration-free environment where holograms can be captured. The laser, optical components, holographic film and object to be captured in the hologram will all be held securely in place by setting them on, or partially burying them in, the sand as shown in Figure 4.

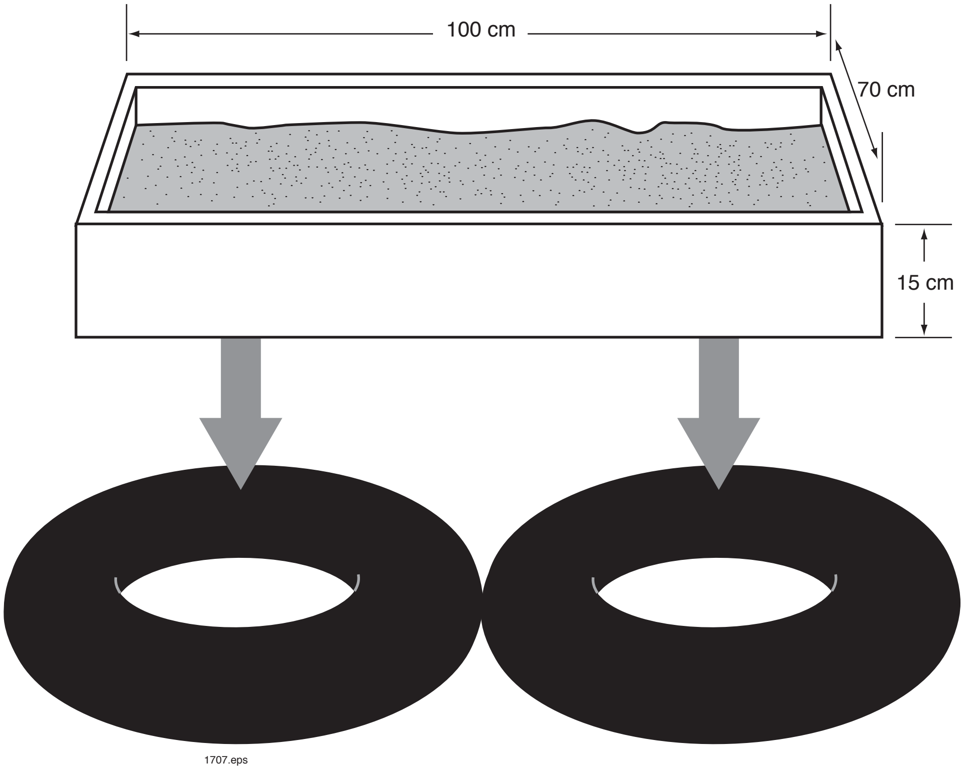


Figure 3. Completed sandbox with innertubes.

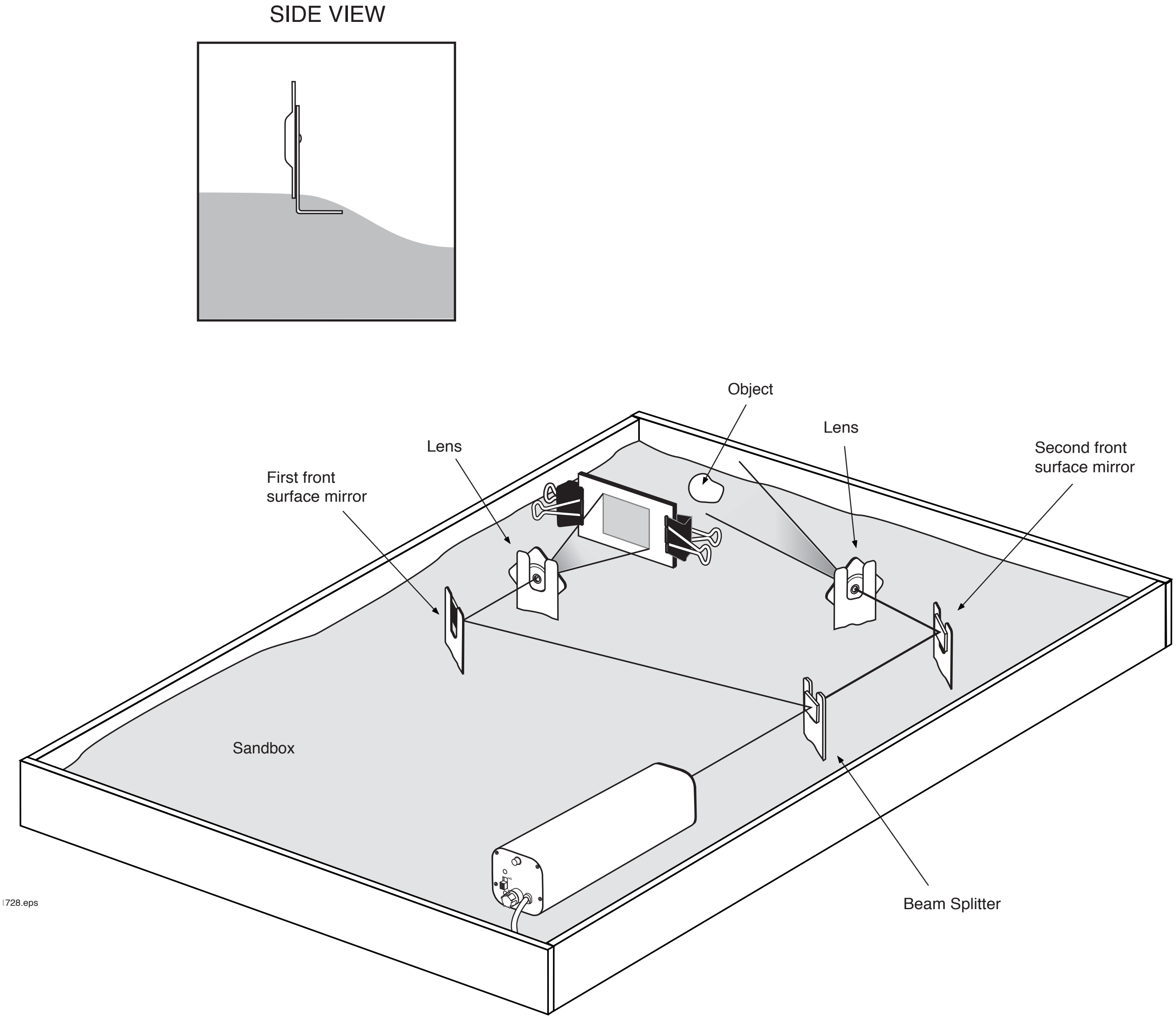


Figure 4. Typical holography setup in the sandbox.

SETTING UP AND EQUIPPING HOLOGRAPHIC STUDIO

The next step is to set up and equip a work area where the hologram can be exposed on film, and the film developed. The following sections describe the elements needed to create a suitable work area.

Setting Up a Darkened Work Area

The holographic film used with this kit is not nearly as sensitive to light as regular photographic film. Its light sensitivity peaks at about 630 nanometers, in the red region of the visible spectrum. The film is relatively insensitive to light of most other wavelengths, especially to wavelengths of about 530 nanometers, the dark green region of the spectrum. Because of this, a true photographic darkroom environment is not needed. The work area should be suitably light safe for exposing and developing the film if all that can be seen are the silhouettes or outlines of objects in the room. A small amount of ambient light is unlikely to affect the film unless it is left exposed to light for extended periods.

An interior room or closet with no windows would be ideal, even during daytime hours. Working at night with all lights out, doors shut and windows covered would also suffice. If working during the daytime in a room where daylight cannot be completely blocked with existing curtains or shades, use black or dark green plastic garbage bags or painting tarps to block out the remaining light or filter out all wavelengths except for dark green.

If so much light is blocked out that the room is too dark to work in, a dark green safelight can be used. An appropriate safelight can be bright enough that a book can be read in the work area, without affecting the film. The Sandbox Holography Kit contains a sheet of dark green filter gel that can be used to construct such a light.

The room needs to be as quiet and draft free as possible. Vibrations from air conditioners, refrigerators and fans can affect exposure of the film, reducing or destroying the quality of finished holograms. Drafts and breezes blowing across the optical elements also can cause them to move slightly during an exposure. Turn off as many of these vibration and draft sources as possible. Vibrations from outside street traffic can also have an effect, so try to choose a room that is as far away from busy streets as possible.

Selecting a Laser

The Sandbox Holography Kit was designed to be used with a helium neon laser. Although other red laser sources may be suitable, we at Industrial Fiber Optics recommend using a helium neon laser. The instructions in this manual assume the use of this type of laser.

The most important characteristic of the laser is that it emits in a TEM_{00} mode. It will have a single, well-defined circular output spot when viewed at a distance, as shown in the upper left corner of Figure 5a. The output will have a Gaussian, or bell-shaped energy distribution, brightest at the very center and smoothly declining in brightness as the distance from the center increases. as shown in Figure 5b. All of the visible, red lasers manufactured by Industrial Fiber Optics emit in TEM_{00} mode.

TEM_{00} helium-neon laser tubes often emit a secondary "ghost beam" along with the primary beam. This beam can be seen as a second, dim laser spot that is visible when viewed near the laser. It is caused by unavoidable internal reflections inside the laser tube. These secondary

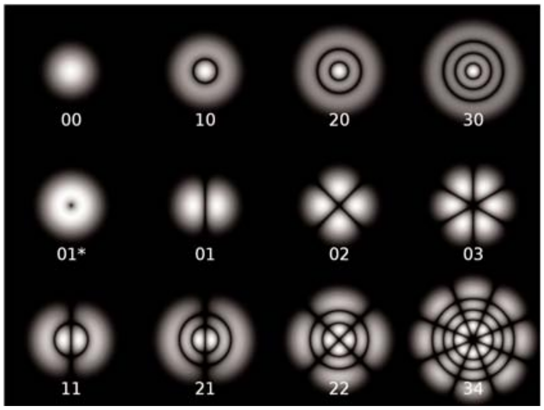


Figure 5a. Examples of Transverse Electromagnetic Modes (TEM_{pl}).

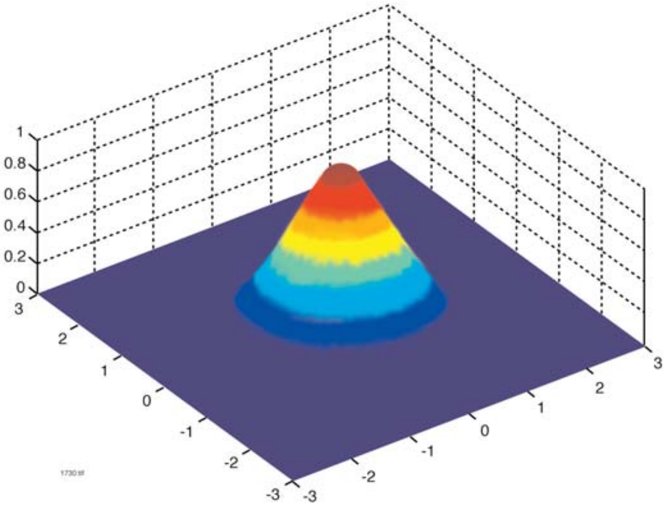


Figure 5b. Graph of a Gaussian energy distribution.

beams are much dimmer than the primary beam (typically less than one percent as bright) and diminish quickly with distance. They will not affect the quality of the holograms being produced.

Another important characteristic of the laser is its output power. The more powerful the laser, the shorter the exposure time of the film needed. A more powerful laser also allows for a wider divergence of the beam to capture holograms of larger objects. More powerful lasers are required for the multiple beam setups discussed in this manual. A relatively low power 0.8-milliwatt laser can be used to make simple direct reflection or transmission holograms of small objects with dimensions of less than two Inches. A 1.5 to two milliwatt laser can be used to make one-mirror holograms. A higher power 3 to 5 milliwatt laser is recommended to make more complicated multiple beam holograms.

Another issue that should be touched on is coherence length of the laser. Coherence length determines the depth of field that can be captured in a hologram. The coherence length of helium neon lasers typically varies from 15 to 30 centimeters, roughly the same length as the tube they use. This is sufficient coherence length to produce holograms of the small objects in this kit. Helium neon lasers are available with polarized or randomly polarized outputs. Either type can be used and will produce good holograms.

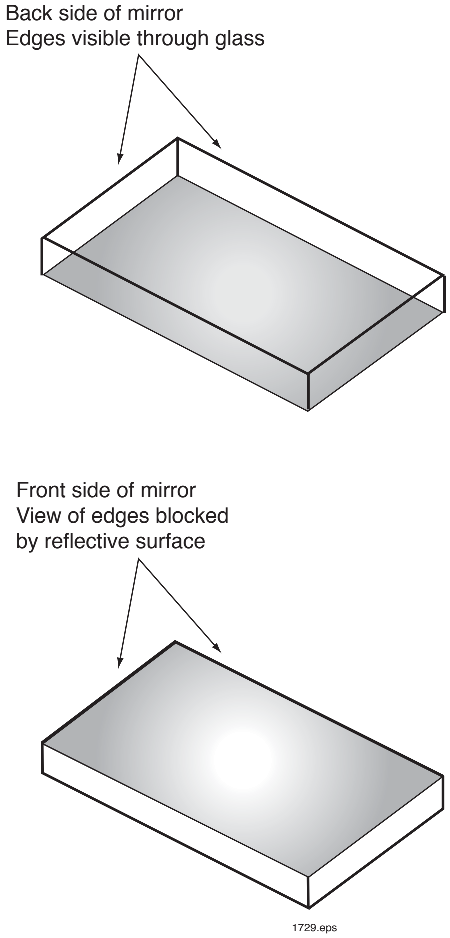


Figure 6. Identifying the “first surface” side of a mirror.

Care and Cleaning of Optical Components

Lenses:

The Sandbox Holography Kit uses plano-concave lenses to diverge the laser beam. If these lenses get dirty or dusty, they will produce unwanted diffraction patterns when the laser beam passes through them. Particles on the surface will produce diffraction patterns resembling ring-like shadows. These diffractions can disrupt the desired Interference patterns on the surface of the film and could degrade or destroy the holographic Image.

Cleaning the lenses can eliminate most of these unwanted diffraction artifacts. Dust and other particles can be blown off the surfaces with a "canned air" type product. More aggressive cleaning can be accomplished with cotton swabs moistened with isopropyl, or rubbing alcohol. Wipe the surfaces of the lens with the damp end and then wipe them dry with the other end.

Mirrors:

The kit uses first surface mirrors. A first surface mirror is one that has the mirrored surface on the front side of the glass, not on the backside, as in household type mirrors. The front and backsides of the mirror can readily be determined. Look Into the mirror at an angle as in Figure 6. If the edges of the mirror can be seen through the glass, you’re looking at it from the backside. Turn the mirror around and note that you can’t see them (the mirrored surface blocks them from view). This is the "first surface" side of the mirror, the side that should be used in the holographic setups. The purpose for using a first surface mirror is to eliminate the multiple reflections that are created by normal mirrors. These multiple reflections will interfere with each other, spoiling the desired interference patterns on the surface of the film.

Mirrors need to be kept free of dirt and dust for the same reasons as the lenses. Particles on the mirrors will produce unwanted diffraction effects similar to those of dirty lenses as the beam reflects around them. The best way to clean them is in a shallow dish of alcohol. Hold the first surface side downward in the alcohol. Without touching the mirror to the bottom of the dish, swirl it around in the alcohol. Allow as much of the alcohol as possible to drain away and then let the remainder air-dry. If more aggressive cleaning is needed, lightly rub a moistened cotton swab on the mirrored surface.

The mirrored surfaces on these lenses are very soft. Care must be taken to not scratch or otherwise damage them. Do not touch the mirrored surfaces; handle the mirrors by the edges only. Oily fingerprints can tarnish the surfaces, becoming permanent blemishes.

Beam Splitter:

A beam splitter is used in some of the setups. In the path of a laser beam, a beam splitter will separate one beam into two separate beams. The beam splitter is positioned at an angle to the beam so part of the light will pass through it and the remainder will reflect off it, creating a second beam. Unlike a first surface mirror, which reflects all of the light striking it, a beam splitter allows some portion of the light to pass through the glass, producing a second reflection as it exits the backside. This second reflection must be blocked or it will interfere with the primary reflection. Do this by taping off half of the beam splitter with opaque black tape. During use, the beam splitter is positioned so the beam is reflected right at the edge of the tape, and the secondary reflection is blocked under its edge as shown in Figure 7. Be sure to keep the beam splitter free of dirt and dust, as with all other optical components.

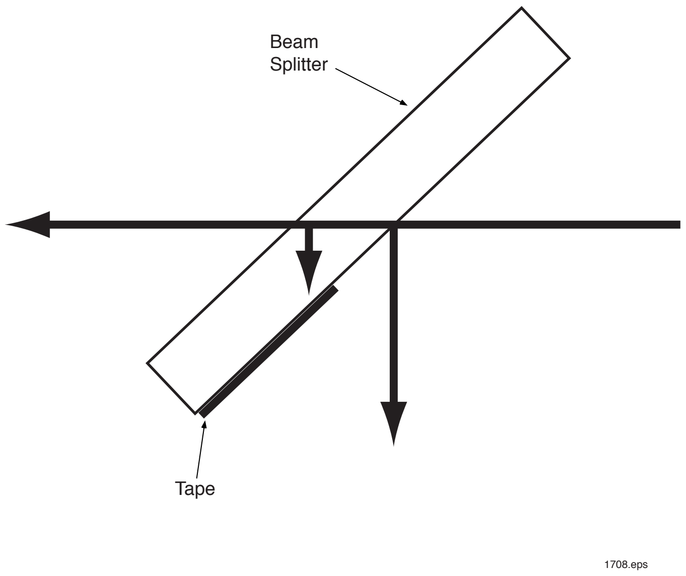


Figure 7. Blocking internal reflections inside the beam splitter.

It can be cleaned with canned air or alcohol and cotton swabs the same as with the lenses.

Mixing and Storage of Developing Chemicals

The chemicals used to develop the film in this kit were obtained from the Photographers' Formulary. All of the developing chemicals should be mixed with distilled water according to Photographers' Formulary instructions in a 1-liter beaker or other glass container. Once mixed, they can be stored in plastic or glass containers with tight fitting lids. Four containers will be required, for parts A and B of the developer, bleach and post treatment. Be sure to label them clearly as photographic developing chemicals.

The chemicals have a shelf life of several months if stored properly. Part A of the developer will react to oxygen in the air of a partially full container. You can split the solution into several smaller containers to reduce its exposure to air. Alternately, drop clean solid objects (marbles are one option) into the container to raise the surface of the liquid to the top of the container, forcing most of the air out. The chemicals will also keep better in a cool dark place. Refrigeration is recommended, but if refrigerated, be sure to allow the chemicals to return to room temperature before use.

Preparing a Safelight

A sheet of dark green gel filter included in the kit can be used to fashion a green safelight. You can use this safelight to illuminate the work area with green light that will not expose the film.

Cover a flashlight or low power nightlight bulb with the filter gel, making sure that no unfiltered white light leaks through. The safelight can be bright enough that you'll be able to read a book in the work area, but keep the light at least four feet away from any open film.

Testing the Stability of the Sandbox

The sandbox must be perfectly rigid, and remain perfectly stationary during the exposure of film. If the box, or any of the optical elements inside it, move as much as one-half a wavelength of the laser light during an exposure, the resulting hologram will likely be damaged or completely lost. If you are using a helium neon laser, that movement distance is one-half of 633 nanometers, or 0.0000317 millimeters.

We'll check the stability of the sandbox by using the kit's components to construct a Michelson's Interferometer. Michelson's Interferometers are most commonly used to precisely measure very small changes in distances, and have many applications in science and industry. For this project, you'll use the interferometer to observe vibrations and minute changes in distance between the optical components in the interferometer itself. You will also use the interferometer to determine the "relaxation time" of the sandbox. Relaxation time is the minimum amount of time required for the sandbox to come completely to rest after it has been touched or bumped, or if positions of optical components have been adjusted.

1. Draw two straight reference lines in the sand at right angles to each other. One line should be centered lengthwise in the sandbox. The other should cross the centerline, about 35 centimeters from one end of the box.

2. Check to see whether the laser has a 1/4 x 20 threaded mounting hole on its underside. If it does, use the 1/4 x 20 screw provided in the kit to plug it, to keep sand out of the laser enclosure.

3. Set the laser on one end of the centerline. Aim its beam directly above the centerline. Mount one of the small first surface mirrors on a U-shaped carrier and place it in the sand at the end of the centerline across from the laser. The laser and mirror should be placed as far apart as possible in order to accurately check the stability of the box. Adjust the mirror and carrier so the mirror reflects the beam back to the laser. Aim the reflected beam to a point just above the hole in the laser's aperture where the beam exits, as shown in Figure 8. The reflected beam should not re-enter the laser. It should strike the front of the laser just above the exit hole.

4. Mount the beam splitter on another U-shaped carrier and place it in the sand at the intersection of the two lines so it splits the 90-degree angle between them. The laser beam should pass through the splitter, and the splitter should be positioned at an angle of 45°. Observe that part of the beam emitted by the laser reflects off the splitter to

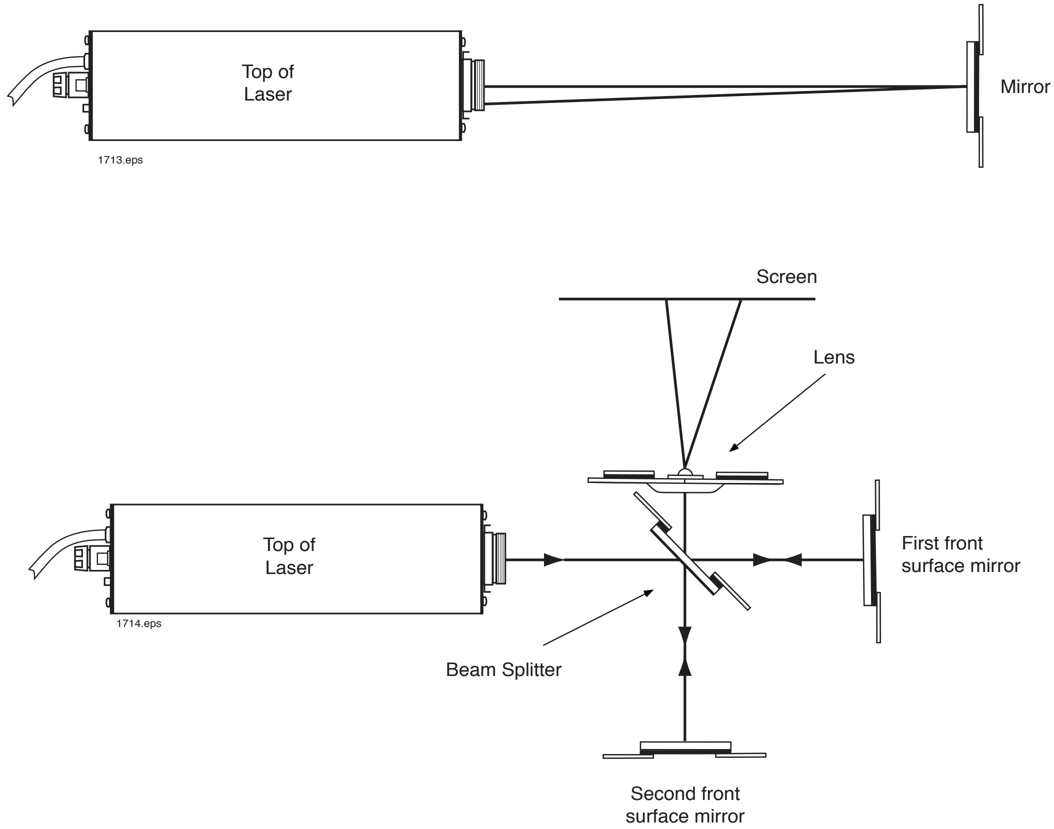


Figure 8. Constructing a Michelson's Interferometer in the sandbox.

one side of the box. Part of the beam returning from the mirror reflects off the splitter to the opposite side of the box. There should be a bright red spot on each side of the box.

5. Fine-tune the position and angle of the beam splitter so both of the beams reflecting off it are aimed above the line in the sand.

6. Identify the beam that reflects off the side of the splitter nearest the laser. Mount a second small mirror on another carrier and place it in the sand at the end of the line, in the path of this beam. This mirror should be positioned the same distance from the splitter as the first mirror. Adjust the mirror and carrier so the beam is reflected back to, and through the splitter. A second bright red spot should appear on the opposite wall of the box.

7. At this point, you may see several dim red spots, caused by secondary reflections from the beam splitter, but they won't affect the performance of the interferometer.

8. Fine-tune the position of the second mirror and carrier so the beam reflected from them converges with the other beam and the two bright red spots merge into a single spot.

9. Mount one of the diverging lenses onto another U-shaped carrier and place it in the sand in the path of the two superimposed beams. Position the lens so the combined beams diverge into an interference pattern of alternating bright and dark areas. These bright and dark areas or fringes are caused by interference between the two beams.

Allow a few moments for the sandbox to stabilize and come to rest. The bright and dark fringes should calm down and become stationary. Watch the interference pattern for a few moments and observe whether the fringes move over time. If they remain still, the sandbox and environment are suitable for holography. Gently tap the side of the sandbox and observe movement of the fringes caused by vibrations from the tapping. Say "hello" to the sandbox, and it will reply with shifts in the fringes caused by your voice vibrations. Stomping on the floor, breathing across the sandbox or even a large truck driving by outside will generate enough vibration to move the fringes. Any movement or vibration that shifts the bright fringes into the dark fringes during exposure of a hologram will damage or destroy the image.

If the fringes do not remain motionless, we can analyze their behavior, determine a cause of the movement and find a solution to eliminate it. If the fringes occasionally move and then settle down, the cause is probably either ground vibrations that are passing through the innertubes or vibrations in the air causing sympathetic vibrations in the sandbox. If the innertubes are overinflated, they will tend to convey high frequency vibrations. If underinflated, they may pass along low frequency vibrations. The cause also might be some rigid object that is conducting vibrations to the sandbox. Is the sandbox or the table it is sitting on touching a wall? Is the counter connected to a wall by a plumbing fixture? Is there noisy activity in an adjacent room?

If the fringes move slowly back and forth, it is probably because of air currents passing over the optical elements. Make sure the air conditioning and any fans are turned off. Close all doors to the work area to keep out drafts from other rooms. Closing air conditioning/heating vents into the work area may help also.

If the fringes move slowly in one direction only, it is due to some part(s) of the interferometer moving slowly. It could be that the sand or the box frame is warming or cooling to room temperature, or that optical components are settling into place in the sand. The sandbox itself could be sagging and deforming under the weight of the sand. Give the setup some time to settle and then check again.

Determining the Relaxation Times

Once the sandbox has come completely to rest and the fringes are stationary, push down slightly on one side of the sandbox frame and release it. Observe fringe movements as the sandbox bounces up and down on the innertubes. Measure the length of time required for the sandbox to come to rest, and for the fringes to stop moving. This is the relaxation time, the amount of time that must elapse between the last time the sandbox was touched, and the time an exposure can safely begin. Observe other relaxation times for different activities that affect vibrations in the sandbox, such as walking around it or breathing across it. It is also important to find the relaxation time of operating the "shutter" that will control the laser's output beam. The beam will be controlled by blocking it with a shutter card placed in the sand directly in front of the laser's aperture. To start an exposure, you will lift the card out of the beam's path, then set it back down to end the exposure. To determine this shutter relaxation time, lean a shutter card up against the laser's aperture. Allow the sandbox to come to rest after the card is put in place. Then gently grasp the card and lift it out of the sand. Lifting it out of the sand will probably create new vibrations that will show in the fringes. Measure the time required for these vibrations to subside completely.

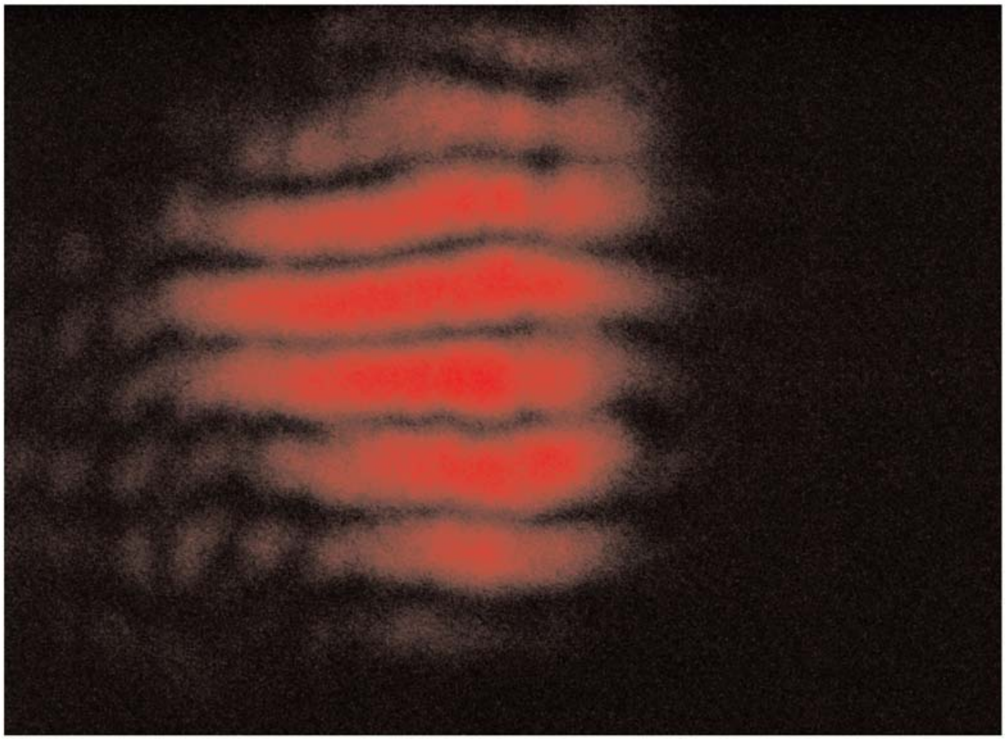


Figure 9. Interference fringes produced by the Michelson's Interferometer.

CAPTURING THE HOLOGRAM IMAGE

Now that the sandbox and holography studio are set up, it's time for us to begin producing holograms. If the laser has a threaded tripod-mounting hole in its bottom surface, it should still be plugged by the screw. Set the laser in the sand and turn it on, allowing it to warm up for at least 15 minutes. (Small variations that occur in the laser's output as it warms up can spoil a hologram if they occur during its exposure.)

Open the laser's beam stop and rest the dark side of a shutter card against the laser aperture to block the beam. You'll raise the shutter card to begin exposing the film, then lower the card to end exposure. This method of controlling the beam is preferable to turning the laser on and off because of possible warm-up variations. If the laser is turned off, it will cool slightly, and then warm back up again when it is turned back on again for the exposure.

Choosing an Object to Record

While the laser is warming up, select an object to be the "star of the show". The object should be made of a rigid material such as plastic, ceramic, metal, etc. Soft, paper or "fluffy" objects often change shape sufficiently during the exposure time to spoil the hologram.

The color of the object to be recorded is important, too. White or off-white objects show up the best in holograms. Red objects also reflect enough of the red HeNe light to work well. Avoid objects that are predominantly blue or green. They will reflect much less of the red HeNe light and appear very dark in a hologram. Also, although metal objects, such as coins work well (small pewter statues are ideal), avoid objects that have very shiny surfaces. A bright reflection emanating from the object can wash out surrounding areas of the hologram.

Determining the Exposure Time

Several different techniques may be used to estimate proper exposure time of the film when creating a hologram. This kit takes a very simple approach by using a calibrated photometer. The photometer is used to determine the irradiance of the diverged reference beams and object beams in a holographic setup in terms of Watts per square meter (that is, the radiant optical power of the beams per unit of area).

The sensitivity of holographic film is expressed in terms of Joules per square meter — the amount of radiant optical energy per unit of area required to fully expose the film without starting to overexpose it. The wavelength of the radiant optical energy also plays a part, as the sensitivity of a given type of film peaks at a specified wavelength, and is much less sensitive at most other wavelengths. The PFG-01 film used in this kit has a peak sensitivity at approximately 630 nanometers, very close to the 633-nanometer wavelength of a helium neon laser.

Since one Watt is defined as one Joule per second, Joules divided by Watts yields seconds. If the required amount of energy is known, and the power of the source providing it can be determined, the amount of time needed to supply the required energy can be calculated by dividing the energy by the power.

$$\frac{\text{Required Energy (Joules)}}{\text{Power of Source (Watts)}} = \text{Time (seconds)}$$

So what does all of this have to do with exposing holograms? Plenty! Sensitivity of PFG-01 film is specified to be between 100 and 150 micro Joules per square centimeter ($\mu J/cm^2$) at the 633-nanometer wavelength of a helium neon laser. This value varies somewhat from batch to batch of manufactured film. If the total irradiance of laser light striking the film during an exposure can be determined, we can calculate an approximate exposure time in the same fashion.

Irradiance can be determined using a photometer by reading the optical power in the center of the diverged beam and dividing it by the surface area of the detector. The surface area of the photometer's detector should be known, specified as "active area" or "aperture diameter" on the specifications page of its operator's manual. If the detector size is specified in terms of aperture diameter, its area can be calculated by $a = \pi r^2$. If the optical power is read out in microwatts and the area of the detector is specified or calculated in square centimeters, irradiance will be calculated in microWatts per square centimeter ($\mu W/cm^2$).

As an example, consider a photometer whose aperture size is specified to be 9 millimeters in diameter. The calculated surface area of its detector would be:

$$\pi * r^2 = 3.14 * (4.5 \text{ mm})^2 = 64 \text{ mm}^2 = 0.64 \text{ cm}^2$$

The first hologram we will capture will be a direct beam transmission hologram, as detailed in Figure 16 on page 21. To estimate the exposure time of this setup, set the laser, diverging lens and object to be captured in position so that the diverged beam uniformly illuminates the object. Position the diverging lens so the diverged circle of light is about one-third larger than the size of the film to be used. But leave the film holder out for now. Position the photometer's detector in place of the film holder and read the optical power on the display. In our example, we will assume a display reading of 25 microWatts. The irradiance in this region would be calculated:

$$\frac{25 \ \mu W}{0.64 \text{ cm}^2} = 39 \ \mu W/\text{ cm}^2$$

Using this irradiance, and the specified sensitivity of PFG-01, an estimated exposure time for the film in this setup can be calculated:

$$\frac{150 \ \mu J/cm^2}{39 \ \mu W/\text{ cm}^2} = 3.8 \text{ seconds}$$

An exposure time of about four seconds would be an appropriate estimate for this setup.

You may have noticed our consistent use of the words 'estimate' and 'approximate' to describe the calculated exposure time. Many factors other than irradiance influence the rate of exposure of the film, and thus the optimum length of the exposure. The angles of incidence of laser light on the object and film have an effect, as do reflective characteristics of the object being captured. In addition, exposure of the film will not be uniform across its entire surface. Like the original laser beam, diverged beams will have Gaussian power distributions, the irradiance of which will be maximum at their centers/less as their edges. That means the film will tend to expose at a slower rate near its edges than in the center.

All of these factors tend to slow exposure of the film, so estimated exposure times calculated by the procedure above will be low estimates.

Optimal exposure times will almost certainly be longer than the estimates, but they are a good starting point. You may need to make several test runs of increasing exposure time to achieve the most satisfactory holograms.

Mounting the Holographic Film

As with all of the other optics elements, the film must be held perfectly still during its exposure. The slightest movement of film will ruin portions, if not all of the hologram. To keep film completely stationary, we must ensure it is held tightly between two glass plates.

Be sure the room lights are turned off before opening the film packet! Turn on the safelight and allow a few minutes for your eyes to adjust to the darkness. Room lights must remain off while the film is mounted, exposed and developed.

1. Determine which side of the film has the emulsion on it. The emulsion is the light-sensitive coating applied to one side of the backing material. The film has a slight curl, or warp. The emulsion is on the inside surface of this curl. In addition, the emulsion side will feel slightly sticky when you touched it with a moist fingertip. Moisten a fingertip and gently touch the inside surface in a corner of the film to confirm that it is actually the emulsion side.

2. Keep track of the emulsion side as you mount the film between the two glass plates. When setting the mounted film next to the object being captured it is important that the emulsion side always face the object.

3. Place the film between the two glass plates (keeping track of the emulsion side) and secure it in place with the two binder clips as shown in Figure 10.

4. Small amounts of air may have become trapped between the film and the plates and must be removed. If an air bubble moves or some of the air escapes during the exposure, the film can move enough to spoil the hologram. Squeeze this air out of the glass-film "sandwich" by pressing it between two wooden blocks, as shown in Figure 11. Apply hard, even pressure for at least 30 seconds.

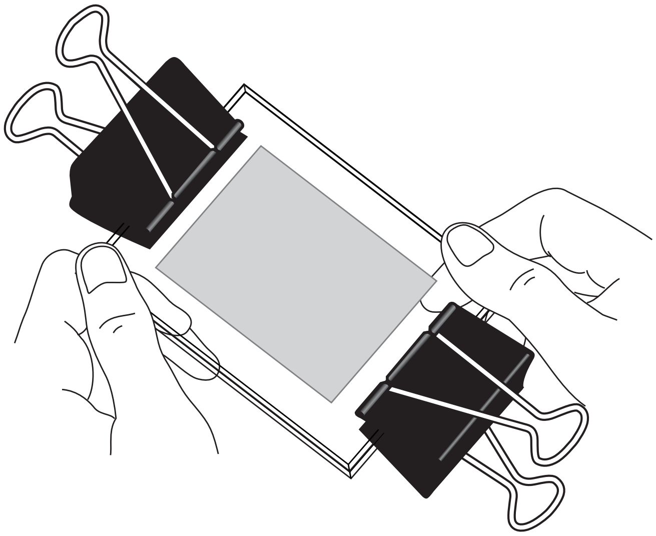


Figure 10. Mounting the film.

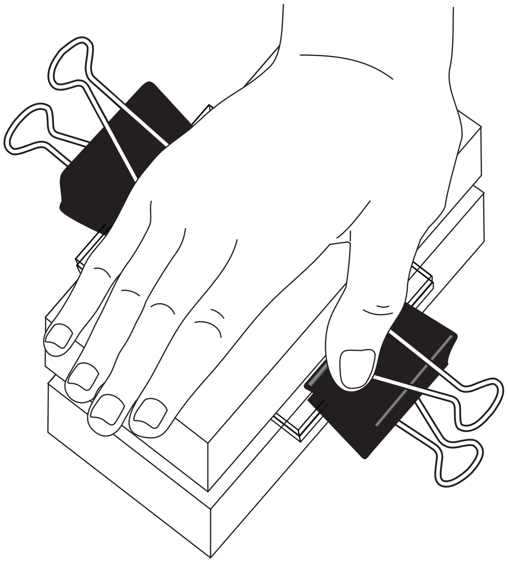


Figure 11. Squeezing out air bubbles.

Exposing the Hologram

By now, your laser should have warmed up for at least 15 minutes. Leave the laser on at all times and use the shutter card to control the beam. Start with the shutter card in place against the laser's aperture. All of the optical elements used in the holographic setup, along with the object being captured, should be in position from when you calculated the exposure in a previous step.

1. Press the film "sandwich" into the sand. (One last reminder: the emulsion side of the film should face the object.)

2. Allow at least the established relaxation time to elapse for the sandbox to stop rocking on the innertubes and for all vibrations to subside.

3. Gently grasp the shutter card and lift it just out of the sand, but not out of the path of the laser beam, as shown in Figure 12. Then allow the relaxation time for lifting the card to pass, to allow any vibration that might have been caused while removing it to subside. The card must not be touching anything, but the beam must remain blocked. There should be a minimum of moving around, and no conversation during this period. Any movement or sound may cause new vibrations to appear in the sand box. Try to control your breathing also. A deep breath close to the sandbox can create enough of a breeze across the sandbox to cause new vibrations or movements.

4. Lift the card out of the beam's path. Allow the laser beam to illuminate the object and film for the intended exposure time, remaining still and quiet. Then gently replace the card against the laser's aperture.

All done! Kind of anticlimactic, wasn't it?

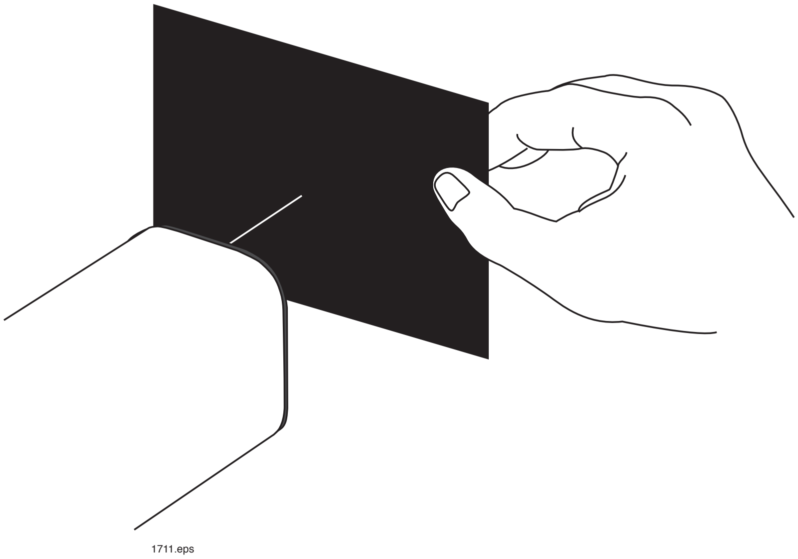


Figure 12. Shutter card raised just before film exposure.

DEVELOPING THE HOLOGRAPHIC FILM

Photographers' Formulary provides a complete set of instructions for developing the film using the JD-3 Developing Kit. A few reminders are appropriate:

1. Keep all lights off except the safelight. Keep the safelight at least four feet from the film until the film has been bleached.

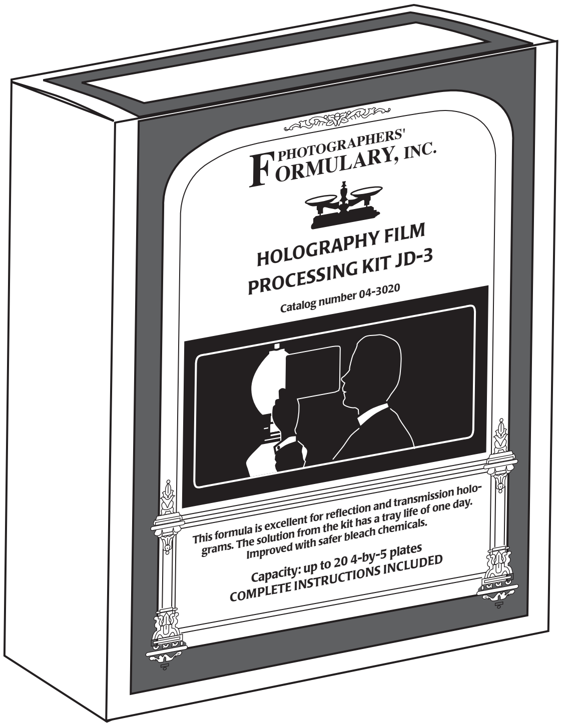
2. Use the smallest containers practical to hold the developing baths, to conserve the chemicals.

3. Be sure to use a pair of tongs or a vinyl glove when developing the film. Avoid direct contact with the developing chemicals.

4. Do not mix Parts A and B of the developer ahead of time. Once mixed, they have a working life of only a few hours.

5. When film is in the developing baths, make sure the emulsion is face up to prevent it scraping against the bottom of the container.

The optional post-treatment is recommended, especially for reflection holograms. It will help to "set" the emulsion, increasing its durability. It will also increase a reflection hologram's resistance to fading from ultra-violet exposure when it is viewed under sunlight. Don't forget that the post-treatment solution gets diluted 10 to 1 with distilled water.



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VIEWING HOLOGRAMS

Reflection Holograms

Reflection holograms can be viewed with either laser light or a point source of white light. Outdoors, the sun is an excellent source. Indoors, a halogen bulb or a clear (un-frosted) incandescent bulb can be used. An overhead or slide projector at a distance, across the room or down a hallway, can also be used. Do not try to view a reflection hologram using a fluorescent light because it is not a point source. The image will be very blurry. If using sunlight, keep viewing time to a minimum. Over time, the ultraviolet content of sunlight will fade the hologram. A diverged laser beam can also be used as a light source.

A reflection hologram works like a mirror. To view it, sit or stand with your back to the light source and hold the hologram up to the light. As with a mirror, the holographic image will appear just behind the film. Although reflection holograms cannot match the depth of field of transmission holograms, they do depict a true change of position of the objects in your hologram when you view them from different angles (that's the phenomenon of parallax at work).

If illuminated by white light, a reflection hologram will have a rainbow-like appearance. Each wavelength of the visible spectrum will reflect off the hologram in a slightly different way, causing a rainbow effect. The hologram may have an overall color of blue or green. If so, its brightness can be increased by exposing it to moist air. Try breathing on it, or holding it over a container of steaming water. The emulsion will absorb some of the moisture in the air, and swell up. As it swells, it will favor reflection of longer wavelengths. The reflected blues and greens will turn to greens and yellows, to which our eyes are more sensitive. We will perceive the hologram to be brighter. If the emulsion continues to absorb more water, its overall color will shift toward red. The swelling of the moist emulsion is why the holographic image cannot be seen when first developed. While soaking in the developing solutions, the emulsion swells so much from the absorbed water that it reflects only infrared wavelengths that are beyond the sensitivity of the human eye. It is in fact creating a holographic image, but the image is invisible to us until the emulsion dries and shrinks.

Transmission Holograms

Transmission holograms must be illuminated by a monochromatic light source to be seen. The best source is the same laser used to create them. Other monochromatic sources can be used, even sources of different wavelengths. However, a source having the same wavelength as the laser used during the hologram's exposure will produce the truest image of the original object.

The laser's beam must first be diverged until it is roughly the same diameter as the size of the film being viewed. Use a diverging lens to do this. Then locate the distance from the lens where the diverged beam just

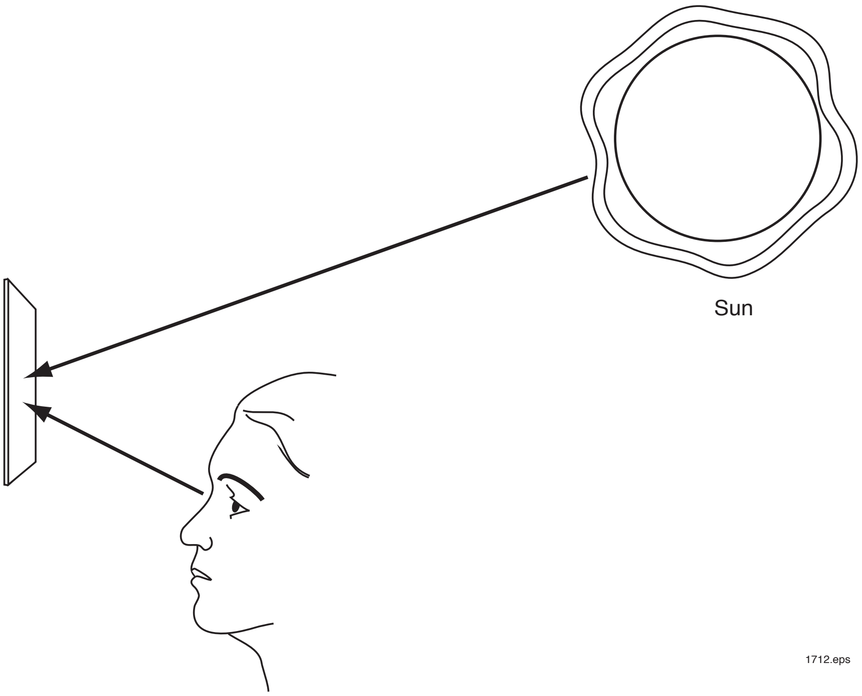


Figure 13. Viewing a reflection hologram.

covers the whole area of the film. Position the film in the diverged beam, and from the side of the film opposite the laser, look into the film as though looking for an object on the other side of a window. Look through the film toward the laser, but not directly into the beam.

NOTE: It is not dangerous to look into the diverged beam as described above. A low powered Class IIIa (less than 5 mW) laser beam diverged to 50 mm or greater in diameter does not pose an eye hazard. Laser users are always strongly cautioned to avoid eye exposure of any collimated beam, but when the beam is this divergent, not enough optical energy can enter the eye to injure it.

Look for an image floating in space on the far side of the film. If you don't see an image, adjust the viewing angle. Depending on the setup when the image was captured, it may be visible only when viewing the hologram from the left, or from the right. The angle of the film with respect to the diverged beam may also need to be changed. The image is visible only when the angle of incidence of the illuminating beam is equal to that of the original reference beam when the image was captured. Some trial and error may be required.

Once the image is "located," vary your point of view of the hologram while holding it in place. As your eyes move up and down and right to left, you will see the objects in the image from different perspectives, just as though they were right in front of you.

Now that you can see the holographic image, cut a small hole two or three millimeters in diameter in a sheet of paper or card stock. Position the paper over the hologram, blocking your view of the hologram except where the hole is. Look through the hole and observe that the entire image is still visible through the hole, appearing from the point of view of that particular position on the film. Moving the hole around on the surface of the film, observe that every point on the hologram contains a complete image of the object.

A two-dimensional image of the hologram can be projected on a screen. Cut a small hole, approximately one centimeter in diameter, in the center of a sheet of paper or card stock. Pass a collimated laser beam first through the hologram, then through the hole in the screen. Hold the screen several centimeters from the hologram. Two projected images will appear on either side of the hole, mirror images of each other. This exercise illustrates that a very small portion of the hologram, in this case the diameter of the collimated beam, contains enough information to project an image of the entire object or scene. You will probably notice that a great deal of detail is lost in the projected images. This is because there is not enough information stored in such a tiny region of the hologram to recreate the image in full detail. But it does contain enough to protect an image of the entire hologram.

Another interesting exercise is to view the hologram using a divergent beam of a different wavelength than the one you used to capture the image. You'll see the image clearly, but it will appear as a different size. It will seem smaller and farther away if a shorter wavelength is used, or larger and closer if a longer wavelength is used.

360° Transmission Holograms

To view a 360° cylindrical hologram, place it back into the jar used to capture it. The emulsion side should be inward. Illuminate the hologram with a diverged laser beam. The beam should shine through the open end of the jar and illuminate one side of the jar's inside wall.

The image should be visible from outside the jar. If you can't see an image, the film may be upside down. Take the film out of the jar and put it back in, with the edge that was originally near the bottom of the jar near the top.

If the hologram was shot using the convex mirror and the light baffle at the top of the jar, the mirror and baffle should be in place. The laser should be aimed directly at the mirror.

Once the image has been located, rotate the jar to see all sides of the image.

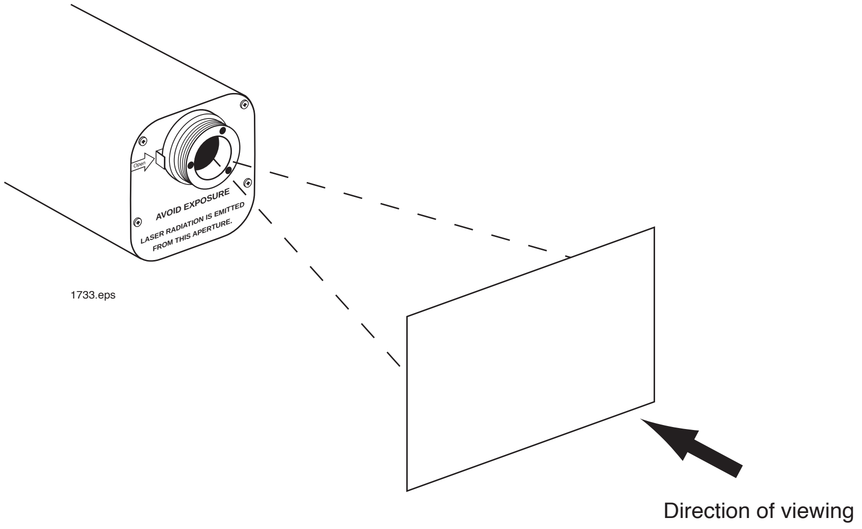
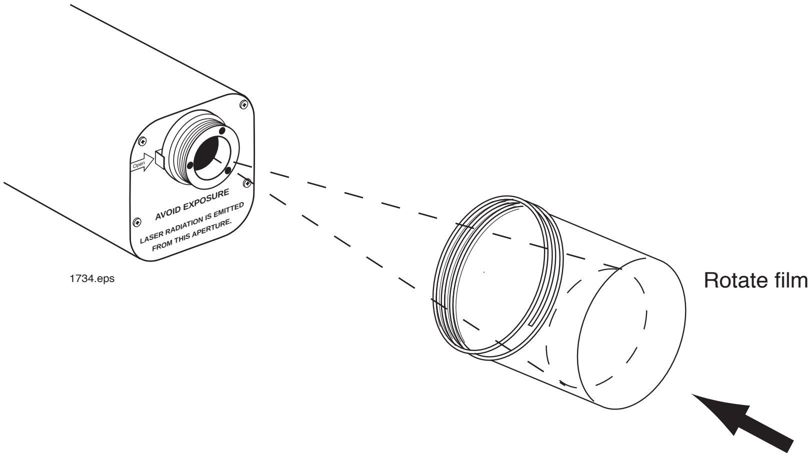


Figure 14. Viewing a transmission hologram.



Rotate film to view all sides of object.

Direction of viewing

Figure 15. Viewing a 360° hologram.

SETUPS FOR CAPTURING HOLOGRAM IMAGES

Direct Beam Reflection Holograms

A direct beam reflection hologram is the best first hologram to try because the setup is simple. Another advantage of this type of hologram is that no laser is required to view it. Many different point sources of white light can be used.

The one disadvantage of reflection holograms is that they cannot be viewed immediately after they are developed. During the development process, the emulsion absorbs water and swells. The image of the captured object cannot be seen until it has completely dried, which may take an hour or more, depending on temperature and humidity.

Some tips and reminders for shooting this type of hologram:

1. The closer the object is to the film, the brighter and clearer the finished hologram will appear. Place the film as close to the object as possible. It is okay for the object to touch the glass plate of the film "sandwich."
2. To reduce the effects of Gaussian distribution of the diverged beam, position the diverging lens so the diverged circle of light is about one-third larger than the size of the film to be used. This will help to even out the exposure by using only the brightest region of the diverged beam. The object and film should be placed directly in the center of the beam.
3. Take a reading of the irradiance in the center of the diverged beam where the film will be placed. Divide the sensitivity of the film by the irradiance reading to estimate the exposure time. Be sure to block the beam with a shutter card (and lights out!) before opening the film.
4. When mounting the film, be sure that all air is squeezed out of the glass-film sandwich. Also be sure the film is placed with its emulsion side toward the object.
5. Be sure to allow appropriate relaxation times to elapse before actually exposing the film.

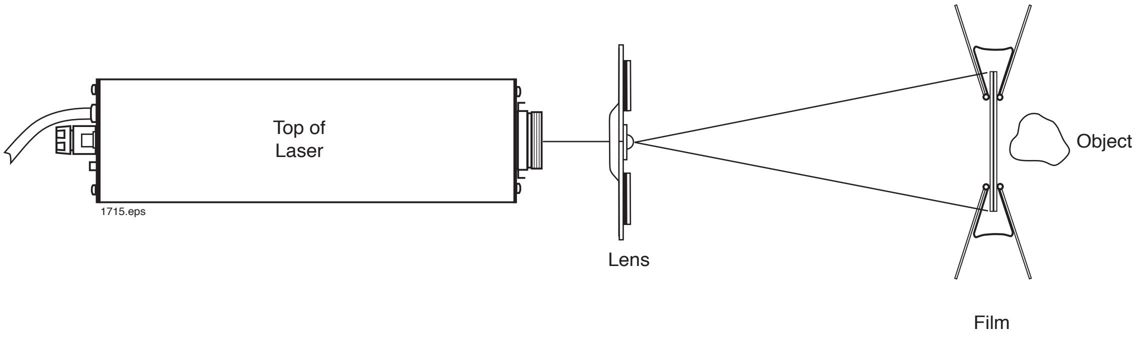


Figure 16. Setup for capturing a direct beam reflection hologram.

Direct Beam Transmission Hologram

Another excellent hologram for a beginner to try is the direct beam transmission hologram. In this setup, objects may be placed a considerable distance from the film. Several small objects may be placed at different distances from the film to create a spectacular display of the parallax and depth of field a hologram can capture.

The main disadvantage of this type of hologram is that objects being captured are backlit by the laser and therefore appear in the finished hologram to be mainly in shadow. As with all transmission type holograms, a laser is required to view the finished hologram.

Some tips and reminders for shooting this type of hologram:

1. Since the objects being captured are mainly backlit, it is important that they be highly reflective, white, off-white, or unpainted metallic. Avoid objects with shiny or sparkly surfaces.
2. Do not place objects directly between the diverging lens and the film. Any shadows of the objects falling on the film will block the reference beam and no interference pattern will form. No holographic image will be captured in this region of the finished hologram — just a gray area with the outline of the object.
3. The laser beam must diverge enough to illuminate both the film and the objects being captured. Adjust the divergence of the beam and the positions of the film and objects to make this so.
4. Take a reading of irradiance at the center of where the film will be positioned, using the formulas we discussed earlier. Use this value to calculate an approximate exposure time.

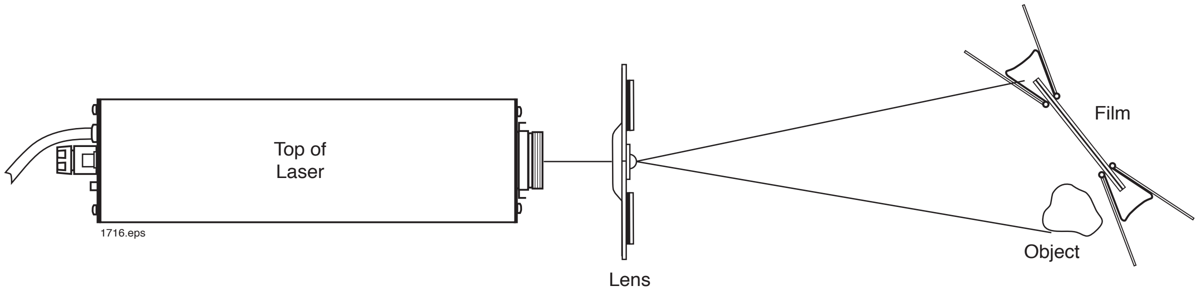


Figure 17. Setup for capturing a direct beam transmission hologram.

One Mirror Transmission Holograms

In this setup we will add a mirror to illuminate the front side of the object being captured. The captured image will have the parallax and depth of field of the direct beam hologram, and the object will be brightly lit.

Some tips for shooting this type of hologram:

1. Use a shutter card as a light baffle to keep the divergent beam from shining directly on the film. In this setup, light reflecting off the mirror serves as the reference beam.

2. Avoid placing objects between the mirror and the film. As with the direct beam transmission hologram, shadows in the reference beam will keep holographic images from forming.

3. In this setup, a reference beam reflects off the mirror, and an object beam reflects off the object being captured. It is important that the ratio of the irradiance of these two beams be between 3 to 1 and 5 to 1 where the film is to be placed. Take readings of the irradiance of each beam by placing the photometer detector at the location of the film. First, block the light reflecting off the object with a shutter card, then read the irradiance of the reference beam reflecting off the mirror. Then move the shutter card to block the light reflecting off the mirror and read the irradiance of the object beam reflecting off the object. Fine-tune the positions of the mirror and object so the ratio of the irradiances is between 3 to 1 and 5 to 1.

4. Add the values of the two irradiances and use their sum to calculate an estimate of the exposure time.

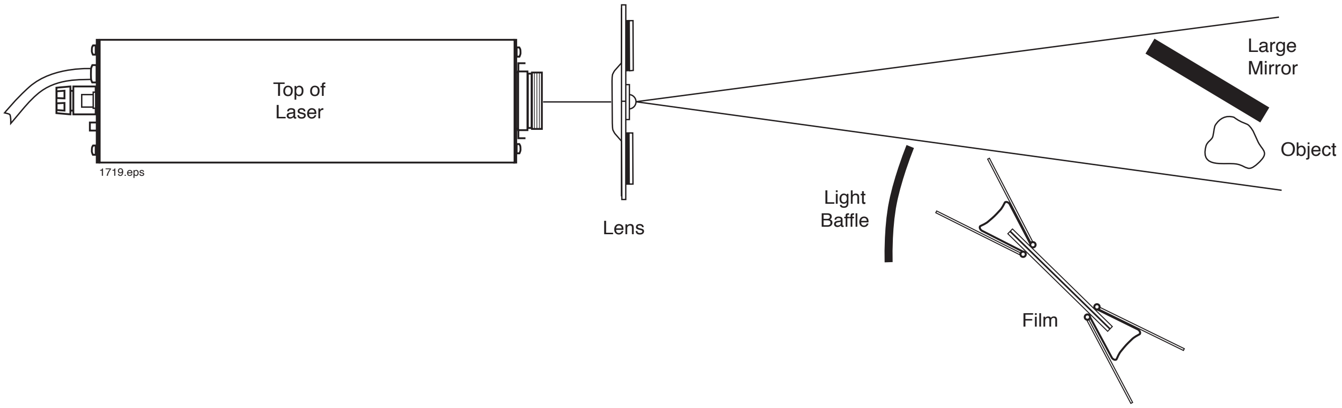


Figure 18. Setup for capturing a one mirror transmission hologram.

Direct Beam Cylindrical Hologram

Cylindrical, 360° holograms create an image of all sides of an object, and are visually spectacular. The finished hologram can be rotated in order to see the object on all sides. The direct beam transmission version of this type of hologram is also relatively simple to set up.

Some tips for shooting this type of hologram:

1. A white playing die (provided in the kit) makes an excellent object to capture. The six different patterns of pips on its faces clearly show that all sides of it are displayed. A plastic bottle cap has also been provided to serve as a stage for the die to rest on. Either set the die on the stage or permanently mount it there with hot glue or quick-setting epoxy.

2. A highly divergent beam is required to shoot this hologram. The beam needs to be diverged enough to illuminate the lip of the jar as shown. Use two diverging lenses, placed as closely together as possible.

3. A 225 x 50 mm strip of film will be mounted inside the clear plastic jar provided in the kit. You'll mount the film strip on the inside surface of the jar's walls. The length of film should wrap completely around the inside of the jar, but not overlap at the ends. The emulsion side of the film should face inward.

   As with all of the other setups, it is crucial that the film not move during the exposure. The chances of the film moving can be minimized by making sure it is pressed against the inside surface of the jar, making contact all the way around. You can also tape the film in place on its top edge.

4. Reflections from the sand or the bottom of the jar can interfere with the desired interference patterns being captured. These reflections can be blocked with black paper. Place a circular sheet of it in the bottom of the jar, large enough to cover the entire bottom surface. You can eliminate reflections off the sand by setting the jar on a sheet of black paper in the sand.

5. Once everything is in place, allow a few extra minutes of relaxation time before beginning the exposure. This will give the film time to finish settling into place in the jar, further minimizing the chances of it moving during the exposure.

6. It is not practical to estimate exposure time for this setup using a photometer. Trial exposures should start at three to four seconds if a 1-milliwatt laser is used, or one to two seconds if a 3-milliwatt laser is used.

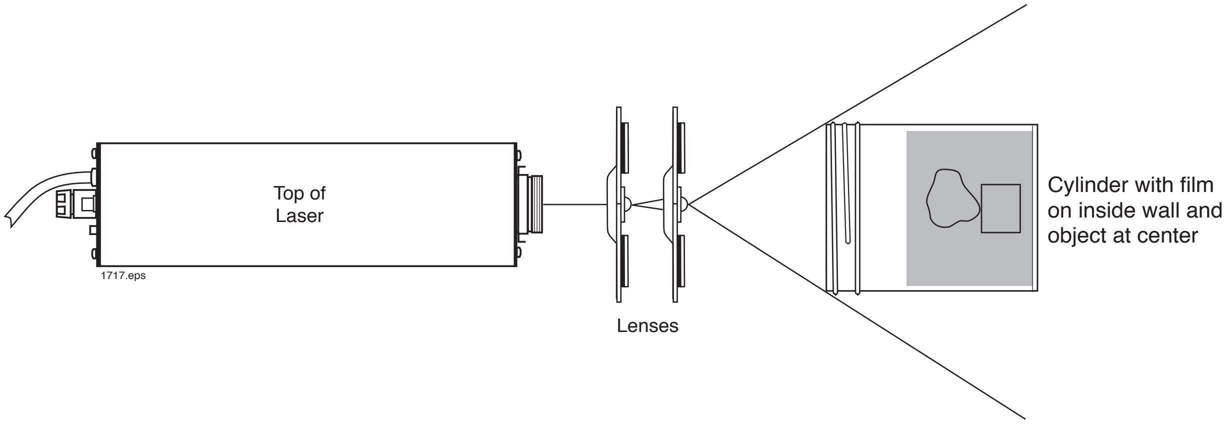


Figure 19. Setup for capturing a 360° transmission hologram.

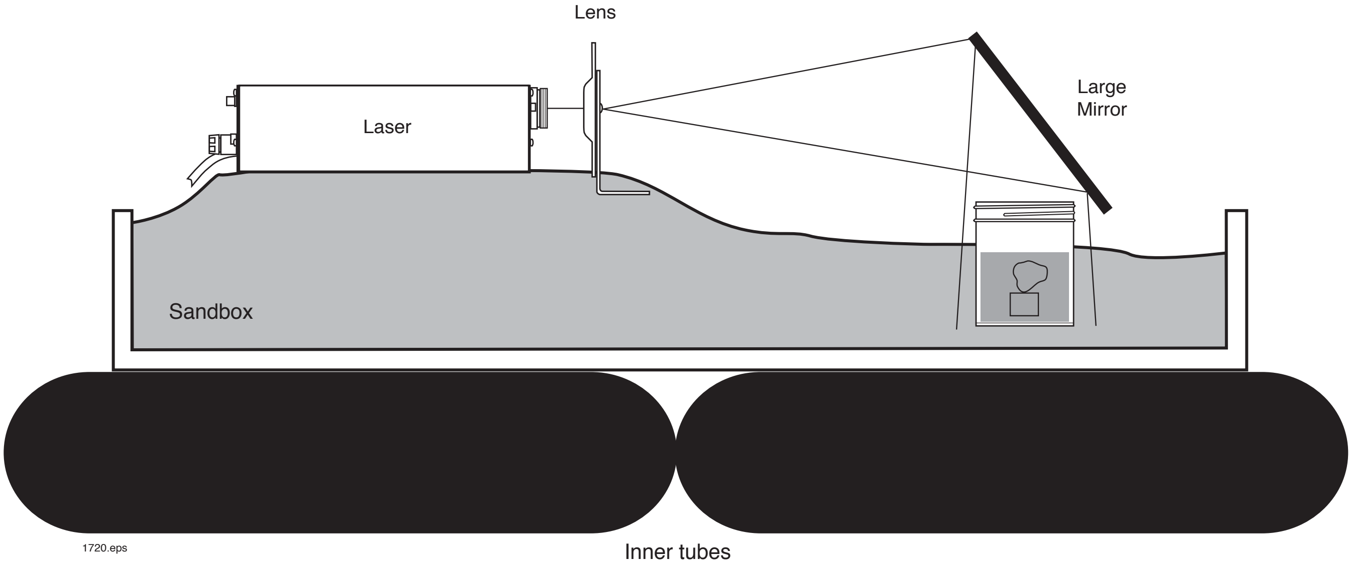


Figure 20. Alternate setup.

One-Mirror Cylindrical Hologram

Adding a mirror to the cylindrical hologram setup increases the illumination of the object and makes it stand out more clearly when viewed.

Some tips for shooting this type of hologram:

1. A convex mirror in the bottom of the jar will reflect the diverged beam toward the film, creating the reference beam in this setup. Place the mirror in the bottom of the jar, on top of the black paper. Set or glue the playing die and stage on the center of the mirror.
2. Since the reference beam is reflected off the mirror, it is important that the light from the diverged beam not directly strike the film. Use the ring of the jar lid as a baffle to block it. Before exposing the film, make sure the entire divergent beam is blocked.
3. Complete the setup and exposure using the direct beam cylindrical hologram instructions found earlier in this manual.

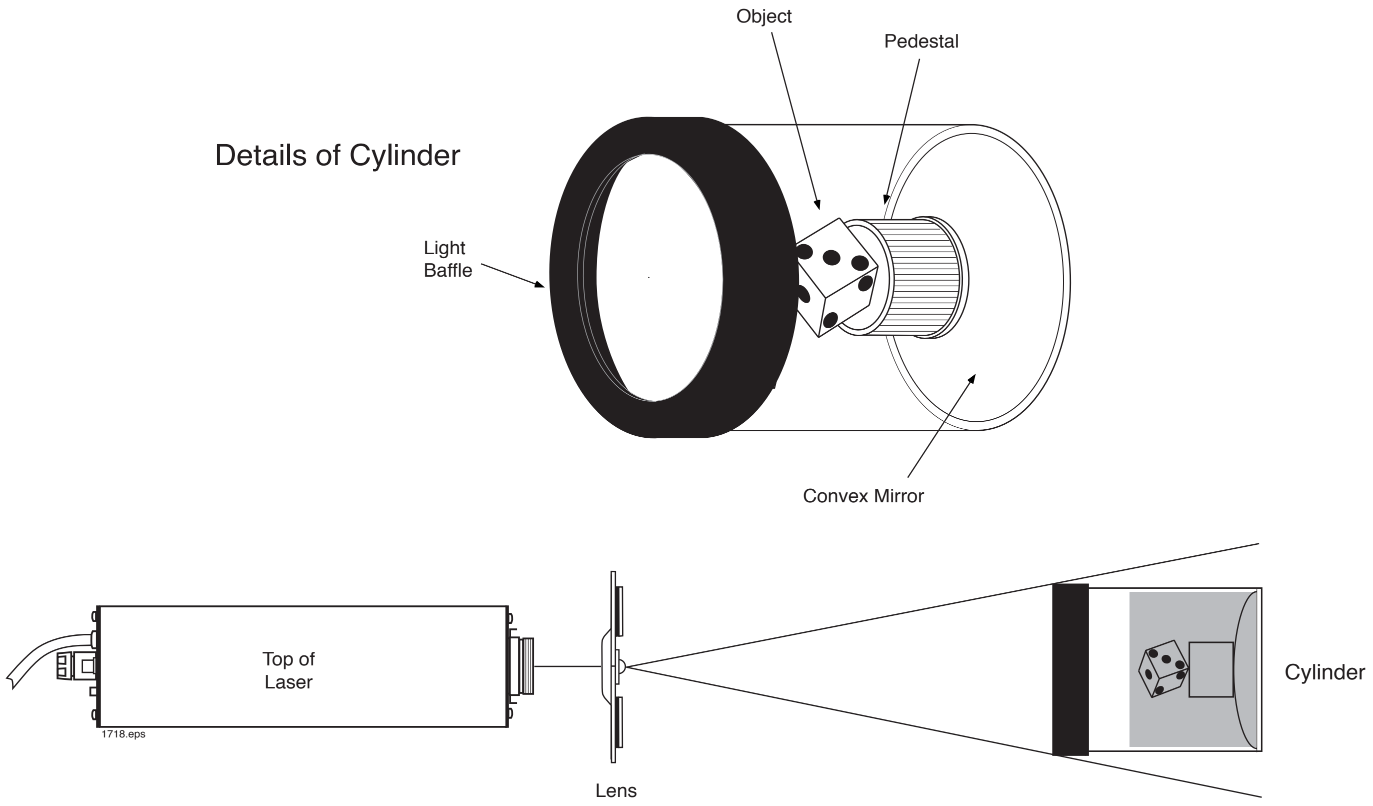


Figure 21. Setup for capturing a one mirror cylindrical hologram.

Multiple Beam Transmission Holograms

A big drawback of the single beam holograms described thus far has been our very limited control over illumination of the objects being captured on film. However, by using a beam splitter, the laser beam can be divided into two parts, allowing far more flexibility in controlling the direction and intensity of both the reference and object beams. Better control of the object beam allows for more control over how the object is illuminated. Increased control of the intensities of both beams allows better control of the ratio of their intensities. Figure 22 and Figure 23 illustrate two practical setups that can be used.

Some tips for shooting this type of hologram:

1. Once the two divided beams leave the beam splitter, it is important that the length of their optical paths to the film are as close to equal as possible. Differences in path length will result in a loss of brightness of the captured image. For each beam, measure the path lengths:

   For the reference beam:
   - the beam splitter to the mirror
   - the mirror to the diverging lens
   - the lens to the center of the film

   For the object beam:
   - the beam splitter to the mirror
   - the mirror to the diverging lens
   - the lens to the center of the object being captured
   - the center of the object to the center of the film

   The sum of these distances is the total path length of the beam involved. Another technique is to use a piece of string to track the path of the beam. Both beams should require the same length of string to complete the path.

2. We can adjust beam ratios by moving the diverging lenses. Moving a lens closer to the film or to the object will increase the irradiance of that beam; moving it farther away will reduce it. The optimal

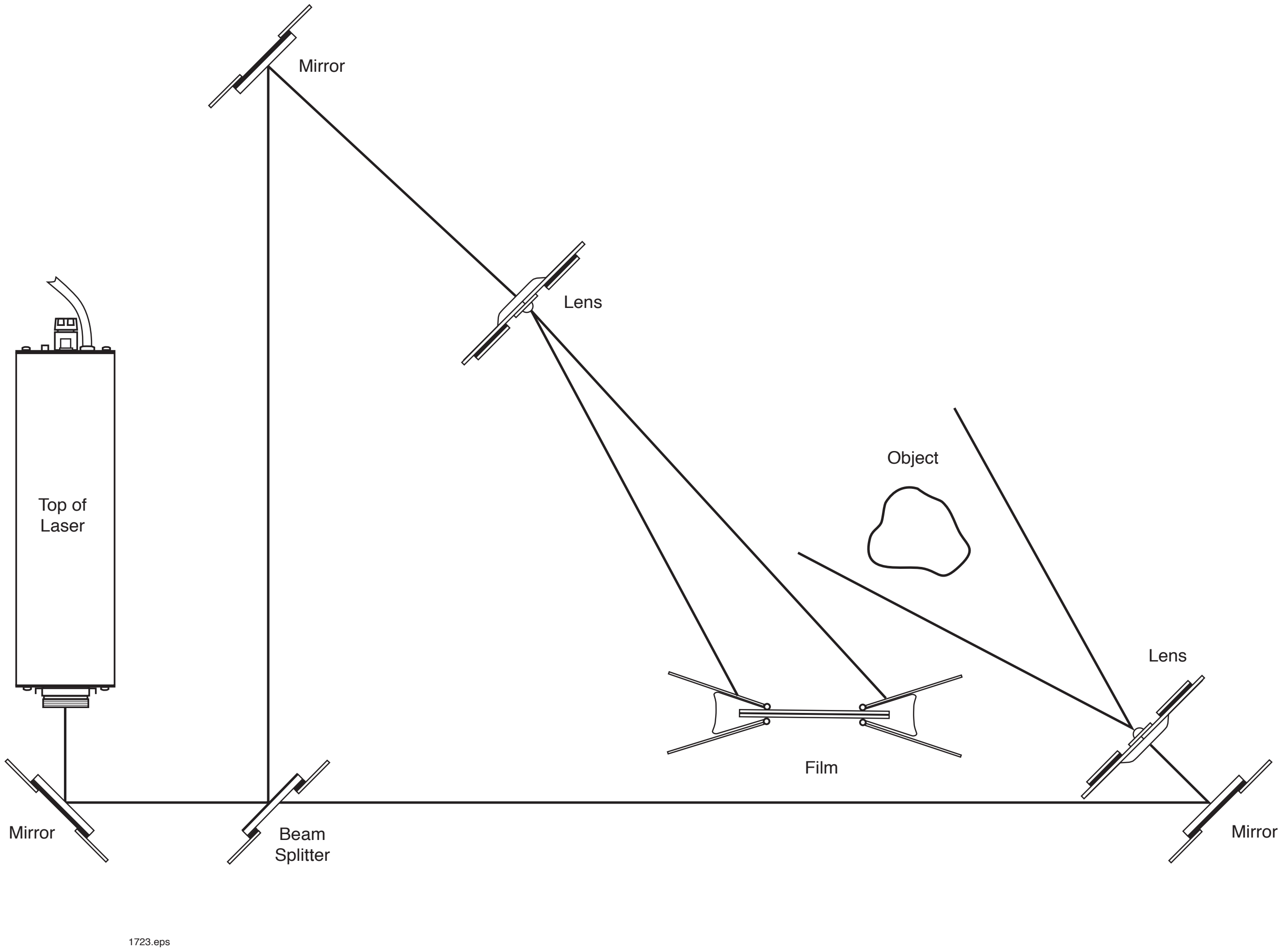


Figure 22. Setup for capturing a multiple beam transmission hologram.

ratio of reference beam to object beam is between 3 to 1 and 4 to 1. As with the one mirror transmission hologram, the ratio is determined by blocking the reference beam, then the object beam, and taking readings of the irradiances. The sum of the irradiances can be used to calculate an estimate of the appropriate exposure time.

3. If the object being captured is large (filling much of the film space available), increasing the ratio will result in a clearer image. Ratios as high as 10 to 1 may be required. If necessary, you can place a lens either upstream of a mirror (that is, the laser beam passes through the lens before reflecting off the mirror) to reduce the irradiance of that beam at the film, or downstream of the mirror to increase the irradiance.

4. The variety of possible multiple path setups is limited only by the creativity of the holographer. A few guidelines should be followed, however. As setups get larger and more elaborate, exposure times will tend to increase. Try to avoid exposure times greater than 15 seconds. The longer the exposure, the better the chance of a movement that might spoil the hologram. You should consider using a higher power laser as exposure times increase.

5. Watch out for light from one part of the setup illuminating other areas. Light striking the film should originate only from the object beams and the reference beam. Any extraneous light reflecting off mirrors or other surfaces that finds its way to the film during the exposure will degrade the quality of the finished hologram. Look closely for these reflections and block them off with light baffles.

   Never design a setup that permits one of the beams to pass over the laser. Heat rising off the laser will distort that beam, possibly spoiling the finished hologram.

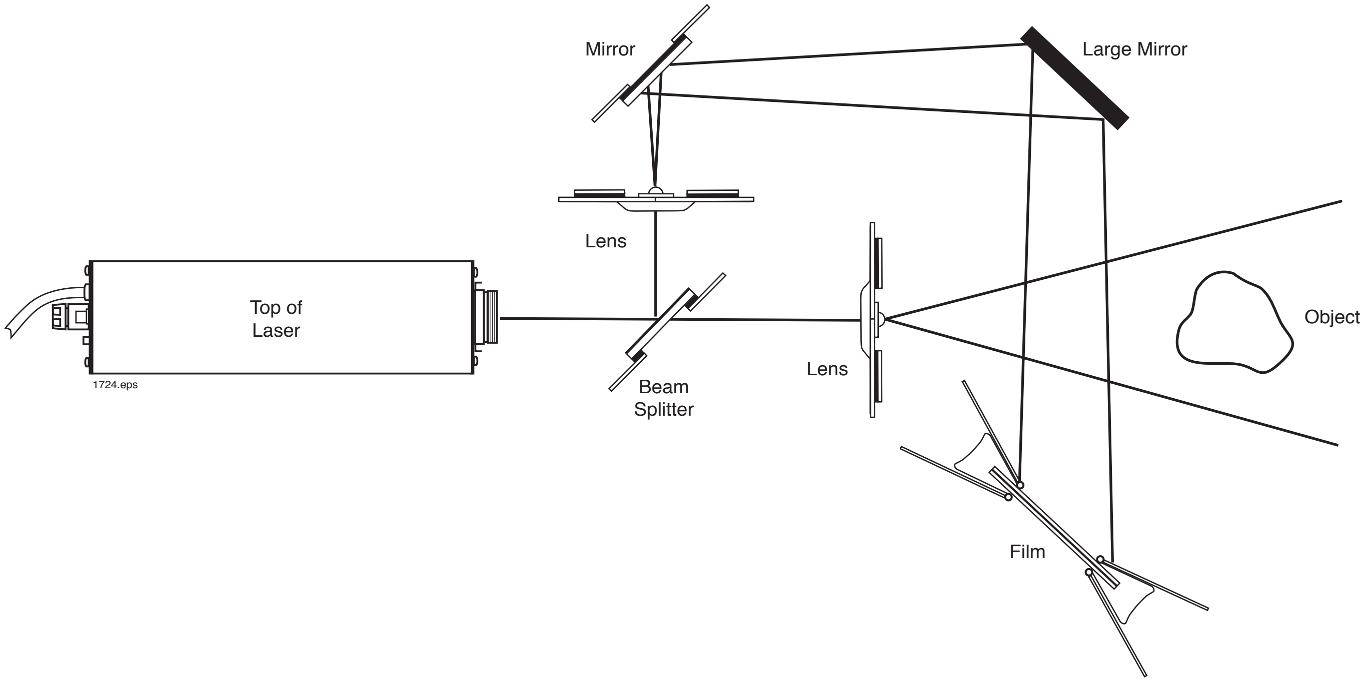


Figure 23. Alternate setup.

Multiple Beam Reflection Holograms

This setup gives the holographer more control of the object beam than in the single beam setup. As with the single beam reflection hologram, the finished hologram can be viewed using white light.

Some tips for shooting this type of hologram:

1. As with the single beam setup, place the object as close to the film as possible, preferably within five centimeters.
2. Keep the path lengths of the object and reference beams equal.
3. The emulsion side of the film should face the object.
4. The ratio of beam irradiances for this type of hologram should be 1 to 1. Adjust the positions of the lenses accordingly.

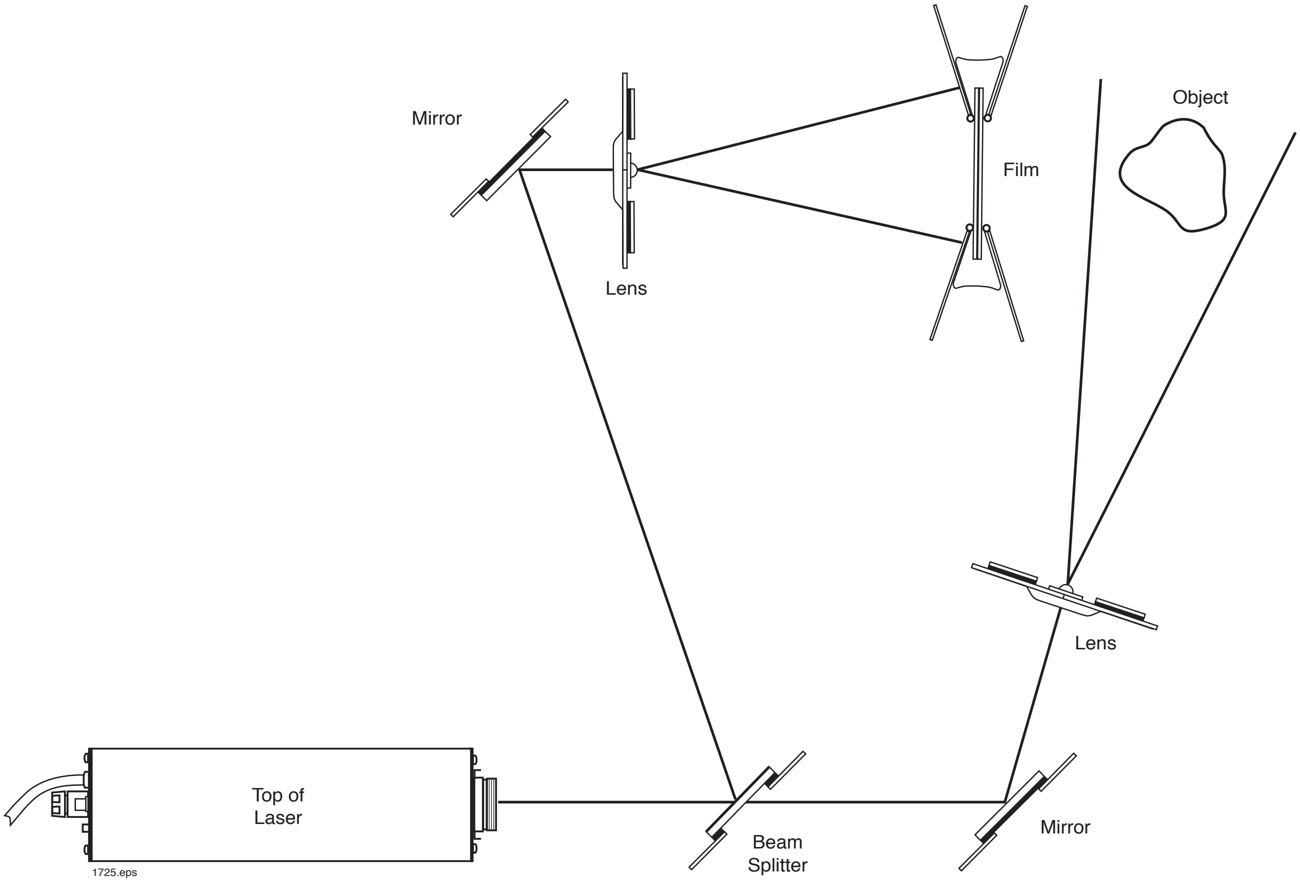


Figure 24. Setup for capturing a multiple beam reflection hologram.

Creative Holography Setups

These are but two of a wide variety of setups that can be used to vary the lighting of the object being captured. The object can be illuminated from several different directions as shown in Figure 25, or soft lighting can be employed to soften shadows as shown in Figure 26. These setups can also be modified to produce reflection holograms.

Some tips for shooting this type of hologram:

1. Remember to keep all beam paths equal.
2. Reference to object beam ratios should be 3 to 1 to 4 to 1 for transmission holograms and 1 to 1 for reflection holograms.

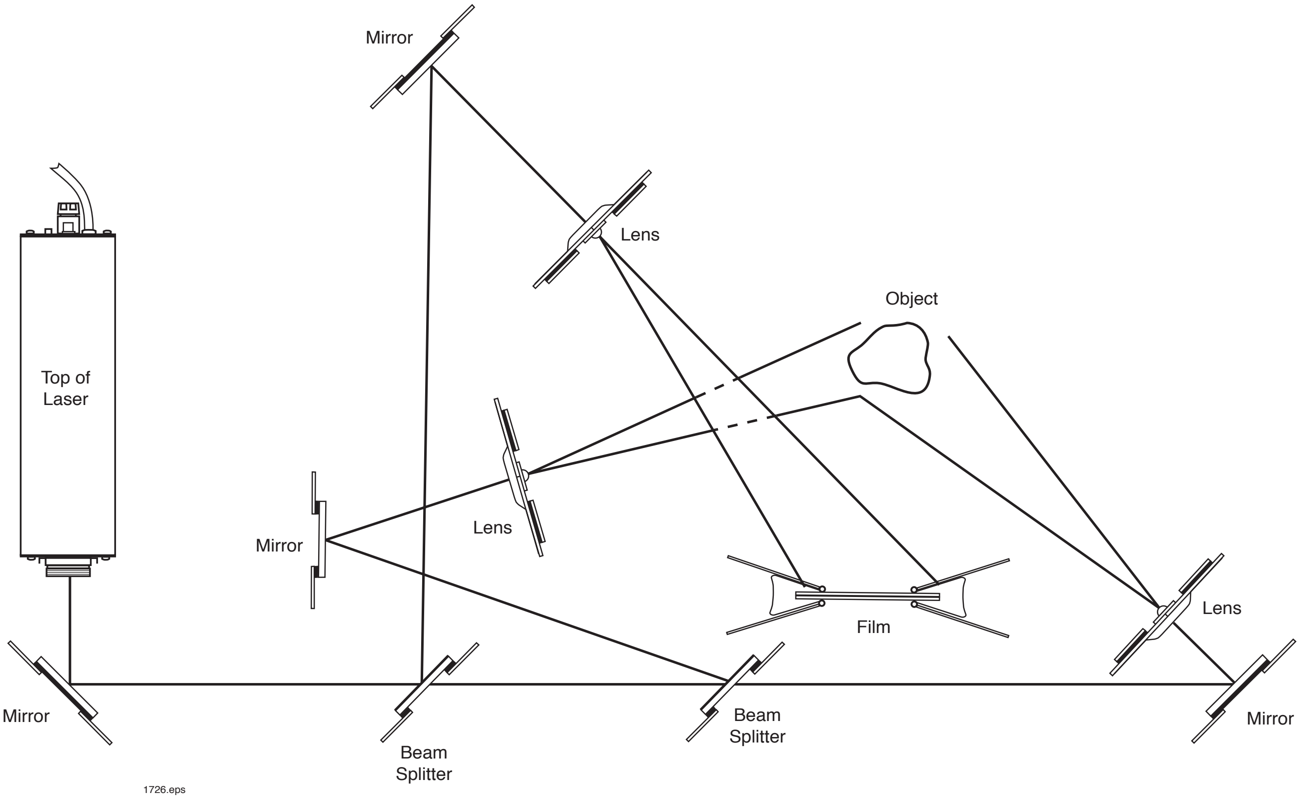


Figure 25. Setup for capturing a hologram using multiple lighting sources.

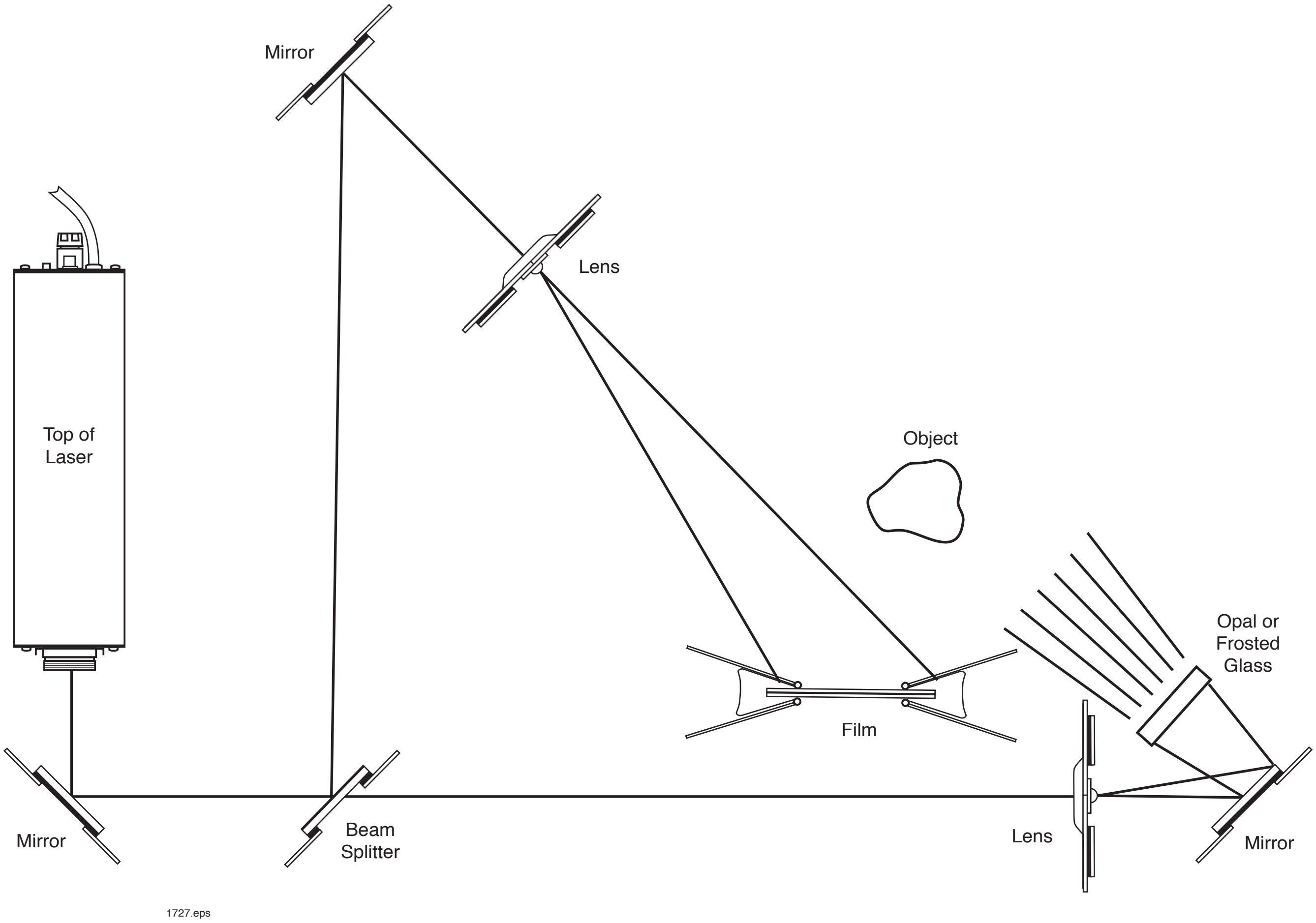


Figure 26. Setup for capturing a hologram using soft lighting techniques.

Multiple Channel Hologram

One of the most important uses of holography is information storage. Holograms are capable of storing a tremendous amount of information or data. In a holographic data storage system, a laser beam is split into a reference beam and data beam, similar to the reference and object beams in a two-beam transmission hologram setup. The data beam is modulated with digital bits, and these bits are written to a photosensitive holographic medium. The two beams intersect inside the medium, and the interference patterns they produce for each bit are recorded, storing the digital data. The reference beam can then be used to read out the data, similar to viewing a transmission hologram.

By varying the angle of incidence of the reference beam, or by using different wavelengths of laser light, we can write many different data sets to the same region of the medium. This multiplexing of data sets in the same place vastly increases the medium's storage capacity. Any one of the data sets written to the medium can be read out by applying a reference beam identical to the one used during its recording.

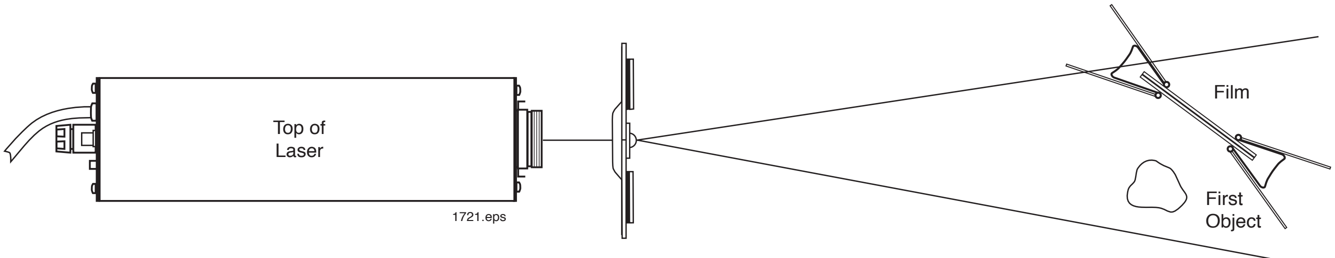
Storage capability of holograms can be demonstrated by capturing several views of an object, or images of several different objects on the same sheet of holographic film. An easy way to do this is by changing the angle of incidence of the reference beam between exposures, as diagrammed in Figure 27. This is analogous to changing the angle of incidence of the reference beam in a holographic data storage system as described above.

There are many other ways to capture multiple images. Try rotating the film 90° between exposures. Alternately, vary the position of an object or the distance between the object and the film. Two views of an object can be captured in a 360° hologram by turning the film upside down (top side of the film turned to the bottom of the jar and vice-versa) between exposures.

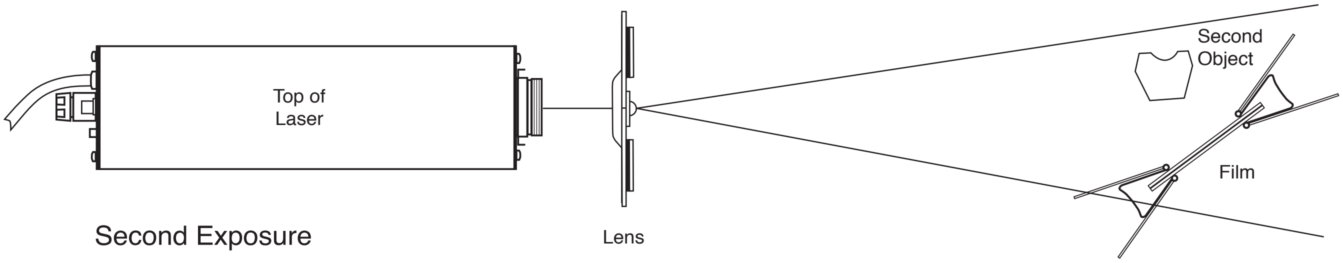
Some tips for shooting this type of hologram:

1. Keep the objects small, or position larger objects farther from the film. Objects that occupy a large portion of the film allow for more interference between images.

2. Exposure times should be approximately the "fraction" of the number of exposures (for example, half as long for two, one-third as long for three, and so on). The practical limit to the number of exposures will be the eventual overexposure of the film, or interference between larger images.



First Exposure



Second Exposure

Figure 27. Setup for capturing a multiple channel transmission hologram.

Holographic Interferometry

Holographic interferometry or holometry can measure even tiny changes in the size or shape of an object. If two holographic images of an object are superimposed, as in a double exposure, any differences will cause interference between them in the areas that changed. This interference will result in visible light and dark interference fringes, each fringe pair representing a 1/2 wavelength displacement.

Real time holometry can be performed by capturing a hologram of an object and superimposing it over the actual object. Any deformation of the object relative to the holographic image will be immediately apparent by the appearance of interference fringes.

The setup diagrammed in Figure 28 uses double exposure holometry to measure the bending of a flexible ruler that supports a small weight. The holographic film will be double exposed, first while the weight is in place, and then again after the weight has been removed. The resulting reflection type hologram will be used to measure the displacement of the ruler. Use a one-foot long ruler that readily reflects red laser light. Fulcrums that support the ends of the ruler should be positioned directly under the one-inch and 11-inch marks. The weight should be positioned at the center of the ruler, at the six-inch line. Tie a string around the weight to help lift it without disturbing anything else in the setup.

Expose the film for about one-half the full exposure time. Then use the string to lift the weight off the ruler, taking care not to touch anything else in the sandbox. Allow a minute or so of relaxation time for any resulting vibrations to subside, then take a second exposure, again for one-half the full time.

Once the hologram has been developed and dried, interference fringes on the ruler should be apparent. Interference patterns should not appear anywhere else on the film. If they do, they indicate the film or other parts of the setup moved between exposures. If the fringes appear only on the ruler, they truly indicate its movement.

Since one of the fulcrums directly under the one-inch line supports the ruler, it would not have moved there. This provides a reference point against which any other movements can be measured. The first dark fringe to the left or right of the one-inch line represents a displacement of 1/4 wavelength, about 0.00015 millimeters for 633-nanometer helium neon light. Each successive dark fringe represents an additional 1/2 wavelength.

Many small changes in size or shape can be studied using this technique. Try capturing two exposures of a mushroom, timed 30 to 60 seconds apart. The growth of the mushroom during this time will be evident in the finished hologram. Or capture the image of a hot metal object, then a second image a few seconds later after it has cooled somewhat. The finished hologram will show the contraction of the object as it cooled.

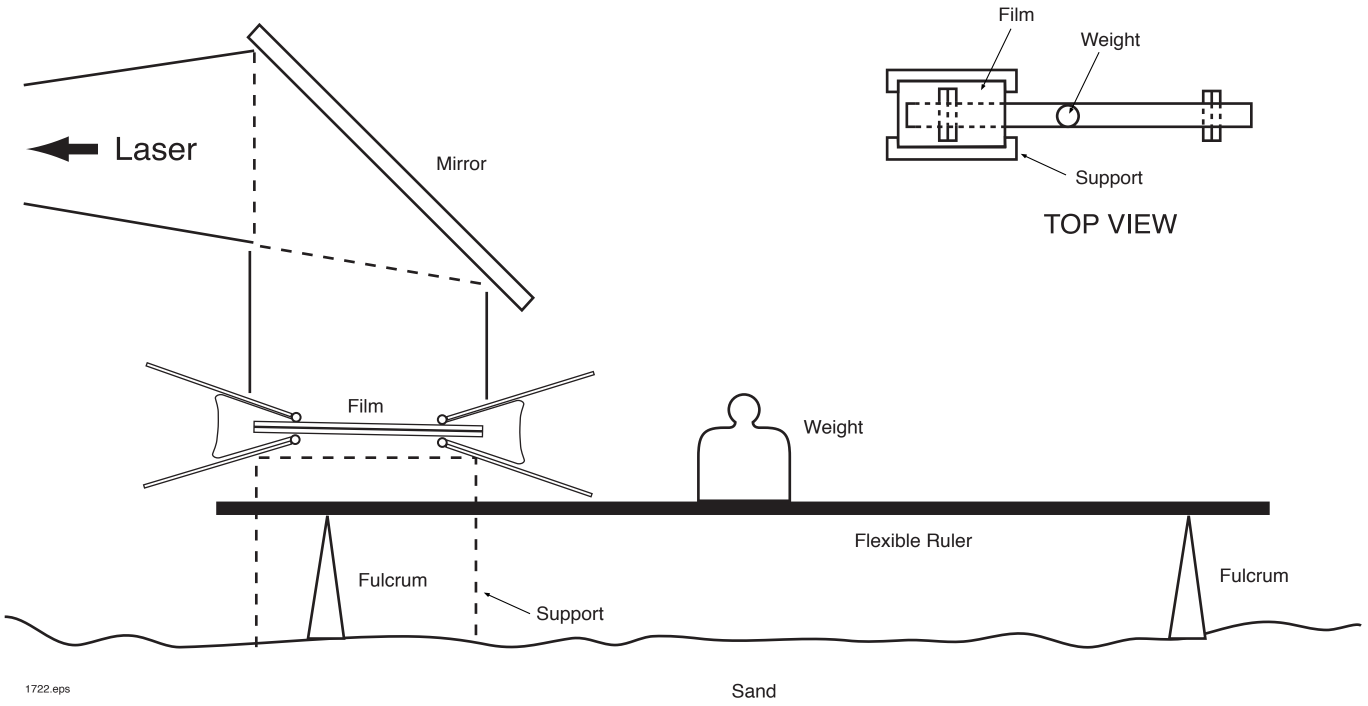


Figure 28. Setup for double exposure holometry.

And that’s it for now.

We hope you've enjoyed this first exploratory journey into the magic world of holograms… and that you've been sufficiently intrigued to continue your studies. This is only one of the many fascinating and functional applications of Industrial Fiber Optics lasers. Please pay us a visit online — www.i-fiberoptics.com — to check out our many other laser (and fiber optics) products. You'll find plenty there to keep you involved in this special and evolving branch of science.

WARRANTY

Industrial Fiber Optics products are warranted against defects in materials and workmanship for 90 days. The warranty will be voided if any of the components have been damaged or mishandled by the buyer, including entry to the receiver housing and/or removal of screws.

Industrial Fiber Optics' warranty liability is limited to repair or replacement of any defective unit at the company's facilities, and does not include attendant or consequential damages. Repair or replacement may be made only after failure analysis at the factory. Authorized warranty repairs are made at no charge, and are guaranteed for the balance of the original warranty.

Industrial Fiber Optics will pay the return freight and insurance charges for warranty repair within the continental United States by United Parcel Service or Parcel Post. Any other delivery means must be paid for by the customer. The costs of return shipments for items no longer under warranty must be paid by the customer. If an item is not under warranty, repairs will not be undertaken until the cost of such repairs has been approved, in writing, by the customer. Repairs typically cost from $50 - $125 and usually take two to three weeks to complete.

When returning items for analysis and possible repair, please do the following:

- In a letter, describe the problem, person to contact, phone number and return address.

- Pack the receiver, power adapter, manual and letter carefully in a strong box with adequate packing material, to prevent damage in shipment.

- Ship the package to:

  INDUSTRIAL FIBER OPTICS
  627 S. 48th St., Suite 100
  Tempe, AZ 85281
  USA

SHIPMENT DAMAGE CLAIMS

If damage to an Industrial Fiber Optics product should occur during shipping, it is imperative that it be reported immediately, both to the carrier and the distributor or salesperson from whom the item was purchased.

DO NOT CONTACT INDUSTRIAL FIBER OPTICS.

Time is of the essence because damage claims submitted more than five days after delivery may not be honored. If damage has occurred during shipment, please do the following:

- Make a note of the carrier company; the name of the carrier employee; the date; and the time of the delivery.
- Keep all packing material.
- In writing, describe the nature of damage to the product.
- In cases of severe damage, do not attempt to use the product (including attaching it to a power source).
- Notify the carrier immediately of any damaged product.
- Notify the distributor from whom the purchase was made.

Notes