A Guide to Creating Holograms

BY LINDA E. LAW

What is a hologram? A hologram is a fully three-dimensional image that is produced when two beams of coherent light interfere with one another and the resulting interference pattern is recorded in a light-sensitive emulsion. This image can be produced in a number of different ways. All holograms require a laser to construct them, but only some require a laser to view them. These latter are called laser transmission holograms. Other types of holograms can be viewed with white light either with the illumination from in front as is seen with white light reflection holograms, or with the illumination from behind, as in white light transmission or rainbow holograms. Rainbow holograms are so called because they shift through the spectrum as you shift your position in front of them. The holograms embossed on the *National Geographic* cover have been put through another process where they are transferred into a photoresist emulsion that creates a surface relief. This pattern can then be embossed into plastic by a stamping process similar to that used to make record albums.

Holograms are being used today in a variety of different applications and are rapidly being incorporated into our everyday lives. Their most obvious use has been on the cover of magazines and most recently on paperback covers. Over 100 million have been embossed onto credit cards. IBM has incorporated them into the scanning system for its supermarket checkout scanners, and British Telecom has developed a telephone credit card that utilizes a hologram. Using a double-exposure technique, which produces a hologram showing the stresses on objects, engineers have found a powerful new tool for testing almost everything ranging from aircraft tires to loudspeakers. Other types of holograms, known as holographic optical elements, are also finding wide application. These H.O.E.'s, as they are commonly known, are finding applications in pilot flight display panels, in cameras (to replace heavy glass lenses), in the production of solar concentrators and in the replication process of expensive optics in a less expensive fashion.

Because of the visual possibilities inherent in the dimensional realism of holograms, artists have been exploring holography as a creative medium for a number of years. Some have gained access to equipment through research facilities, but others have been working with low-cost equipment around the world, producing images that surprise and delight all who see them. Their achievements often astonish scientists who have the luxury of working with the best equipment. This development of low-cost techniques has resulted in holography being incorporated into high school curriculums as well as many workshops in colleges and universities.

Because laser light is essential to the construction of holograms, it is important that the properties of laser light be understood. This is easily accomplished by a comparison of laser light and white light. White light produced by an everyday light bulb is composed of many different wavelengths: it is "out of phase" and it is "incoherent." Laser light, however, is light of one wavelength (and therefore one color): it is "in phase" (all the peaks and troughs are moving together); and it is "coherent" (all the waves are moving parallel to each other). It is these properties of laser light that are exploited when we make a hologram.

We now need to look at what happens when two waves of laser light meet and interfere with one another. If these two waves are "in phase" (in step — ed.) with each other when they meet, they will amplify, forming a larger wave: i.e. they constructively interfere with each other. If they are "out of phase" when they meet they will cancel each other out, i.e. they destructively interfere.

The cancellation and amplification of

A one beam reflection holographic setup.

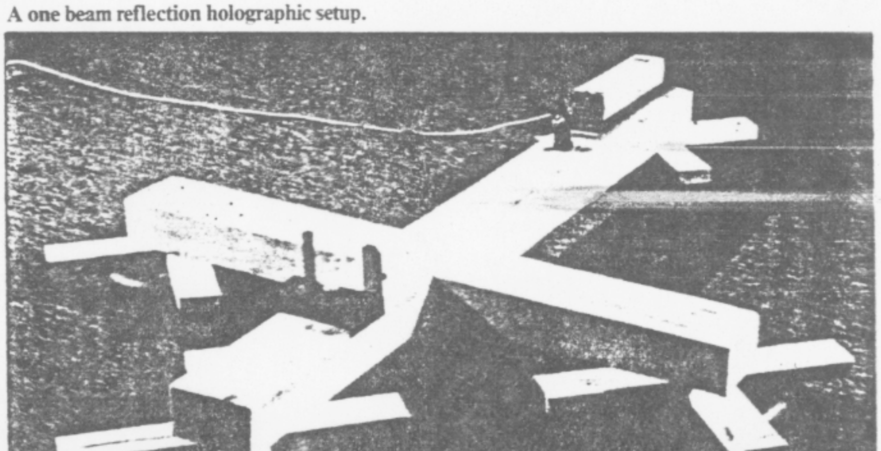


FIGURE 1
MICHAELSON INTERFEROMETER SETUP

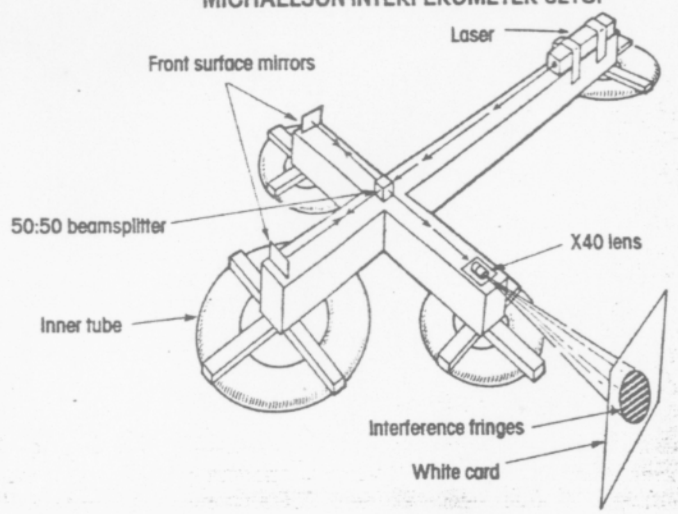


FIGURE 2
ONE BEAM LASER TRANSMISSION HOLOGRAM SETUP

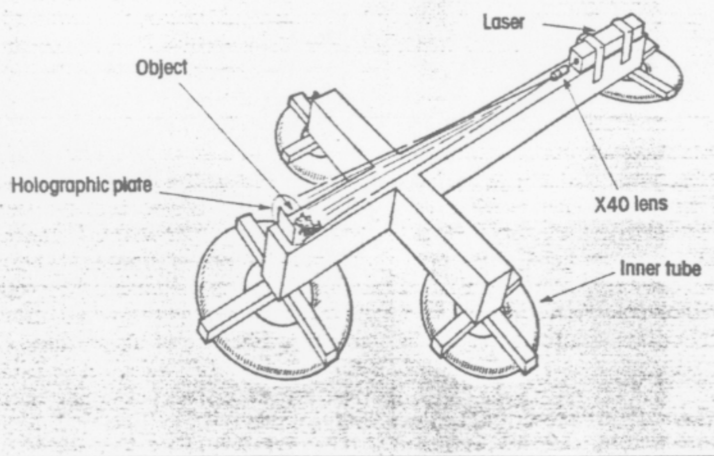
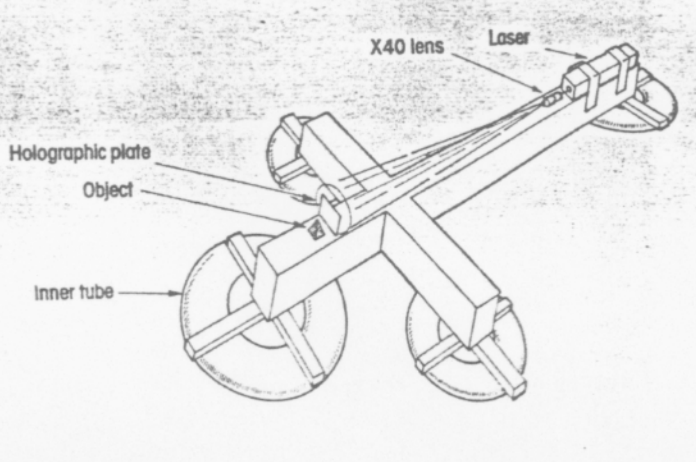


FIGURE 3
ONE BEAM REFLECTION HOLOGRAM



waves interfering with one another forms a pattern of light, the interference pattern, which is recorded in a light-sensitive emulsion and then is processed to form a hologram.

Manipulating the Light Beam

Now let's look at how we manipulate the laser beam to form this interference pattern. In its most basic form an interference pattern is constructed when two beams are brought back together, overlapped and expanded. This is called a Michaelson Interferometer. and it has another application that is useful to holographers which I will explain later on. It is easily formed by splitting the laser beam into two equal parts with a 50:50 beamsplitter (this is a piece of partially silvered glass that reflects half of the light from its front surface and allows the other half of the light to pass through); then each beam is reflected back along the same path with front surface mirrors placed at equal distances from the beamsplitter so that they meet and are joined back together exiting as one beam at right angles to the original beam. This beam is expanded with a lens and the light is allowed to fall onto a piece of white card (see Figure 3). We now have two identical beams of light interfering with each other in line, and an interference pattern is formed of horizontal lines, alternating bands of light and dark.

Before we go any further we must look at a fundamental problem in holography that has to be dealt with if we are to have any success at all in making holograms: vibration isolation. If those two beams that we previously interfered in the Michaelson Interferometer move more than half a wavelength relative to each other, we will not record that interference pattern. Because almost any vibration would cause the beams to move more than that amount, we must isolate our system from vibration. Scientists with large budgets can buy expensive systems with pneumatic legs to damp out vibrations, but we have to employ ingenuity to do this inexpensively. There are a number of ways by which this can be accomplished. The simplest, cheapest and easiest that I have come across is a system called the Big Beam developed by Chicago holographer Ed Wesley. I have modified his original design slightly to produce a holographic vibration isolation system that looks like a large cross resting on four automobile inner tubes. This can be constructed with two lengths of 6″x4″ beam. one 6′ long and the other 4′ long. These should be notched together to give three arms at one end that are each 2′ long and held in place with a wing nut so that they can be disassembled when not in use. Two crossed pieces of 2″x4″ wood rest on a small inner tube (length of these crossed pieces will depend on the size of the inner tubes). The total cost of these materials should be under $30.

We now have a simple vibration isolation system, but before we can use it we must do a few things to increase our chances of eliminating all vibration. The location for the table is very important. I would highly recommend that anyone building this system only consider setting up in a basement area, on a concrete or stone floor, away from any boilers or potential sources of vibration. Most holographers using low-cost systems work in such locations. Sources of serious air currents (air conditioners, fans, etc.) should also be considered, as well as sources of noise. The inner tubes must also be underinflated. If they are pumped up too hard they will not damp vibrations but simply transmit them.

The Key Component

Now for the laser. This is the most expensive item in this whole system, and serious consideration should be given to its purchase. I would recommend a 5mW Helium-Neon laser that is linearly polarized. It is possible to make holograms with randomly polarized lasers, but the linear polarization allows you to use all of the light emitted by the laser more efficiently. Helium-Neon lasers produce a red light with a wavelength of 633 nanometers. These lasers can be purchased from a number of companies for around $500. This 5mW HeNe is a relatively low-power laser that can be used quite safely if one or two simple rules are observed. You should NEVER look down the beam of a laser, as this would mean that the beam would be pointing straight into your eyes. Although a 5mW beam is very low-power, when it passes through the lens of your eye it is focused down to a very small spot. This means that the energy in the beam in the form of heat is concentrated onto your retina and an irreversible burn may result. The unfocused beam does not have enough heat for you to even be able to feel it on your skin, but it is a different story after it is focused by the lens in the eye.

The Michaelson Interferometer

Now that we have a laser we'll construct our first setup, a Michaelson Interferometer, and test our system to see just how stable it is. To build the interferometer we need to purchase a few optics and make a few simple mounts for them. We need a 50:50 beamsplitter, two front-surfaced mirrors, a lens and a piece of white card. A hot glue gun is also a very useful tool to have around. The laser must be firmly fixed onto the end of the long arm of the Big Beam. This can be done by strapping it to the table with those elastic straps cyclists use to hold packages onto their bicycles and screwing a couple of hooks into the beam to attach them to. Beamsplitters, front-surfaced mirrors and inexpensive lenses may all be bought from Edmund Scientific Co., a useful resource for beginning holographers. Total cost for the optics needed to construct all of the systems described here should be under $150.

Once the laser is fixed into position. the beamsplitter must be mounted firmly in place. The height of the beam must be measured and a mount for the beamsplitter must be designed so that the beam passes through its center. This can be done by using a small block of wood that is notched to hold the beamsplitter and then gluing the beamsplitter firmly into it with epoxy for a permanent bond or with hot glue for a temporary one. The block should be planed as flat as possible and then glued into place on the beam with hot glue. The mirrors must also be mounted on the beam at equal distances from the beamsplitter. Do not glue these into place until interference fringes are seen, as some adjustments may be needed to obtain them. The mirrors should ideally be mounted onto adjustable mounts, which allow you to fine-tune them. These can be purchased (Edmund Scientific again), but it is possible (although more tricky) to do this with the mirrors fixed in place. Once you have the two beams emerging together from the beamsplitter, they must be expanded. This is done by passing the beam through a 20X or 40X microscope objective. Again, the objective can be bought from Edmund Scientific and must be mounted in place at the right height in the beam. The expanded beam, when allowed to fall on a white card, should show alternating black and red bands, or fringes. If you don't see fringes, check that both beams are lined up correctly when they enter the beamsplitter and that the beam paths to the two mirrors are equal. Try moving one of the mirrors backward and forward a little until the fringes are seen. Adjusting these distances will also allow you to change the width of the fringes. Try to get large fringes. Now that we have built our interferometer we can test the whole system for stability.

The Michaelson Interferometer will respond to any movement in the system and will show you exactly where you may have problems. First of all, you should gently tap each of the components in the system. You will see the fringes move, but they should damp out quickly. Any optic that continues to move will produce moving fringes and must be more firmly fixed into place. Hot glue is very good for this. Now we can also test the stability of the whole systems. Stamp on the floor, clap your hands, bang on the wall, watch what happens when your boiler cuts in, when the telephone rings, when someone slams the kitchen door. If these things make the fringes move, you must make sure that they do not happen during your exposure. If you see any drifting in the system or a regular vi-

Distributors of Laser Components

Helium Neon Lasers are available from the following companies:

Jodon Laser
5214 Jackson Road
Ann Arbor, MI 48103

Melles Griot
Laser Products Division
435 S. Pacific Street
San Marcos, CA 92069

Metrologic Instruments, Inc.
143 Harding Avenue
Bellmawr, NJ 08031

NEC Electronics, Inc.
401 Ellis Street
Mountain View, CA 94039

Spectra-Physics
Laser Products Division
1250 W. Middlefield Road
Mountain View, CA 94039

Low-cost optical components can be obtained from:

Edmund Scientific Co.
7782 Edscorp. Building
Barrington, NJ 08007

Jodon Laser
5214 Jackson Road
Ann Arbor, MI 48103

Metrologic Instruments, Inc.
143 Harding Avenue
Bellmawr, NJ 08031

Holographic plates can be obtained from:

Integraf, Inc.
745 North Waukegan Road
Lake Forest, IL 60045

Jodon Laser
5214 Jackson Road
Ann Arbor, MI 48103

Newport Research Corporation
18235 Mt. Baldy Circle
Fountain Valley, CA 92708

bration, you must track down where it is coming from and eliminate it or you will have problems when you try to record a hologram.

The Hologram

With the system in place we are now ready to attempt our first hologram. The following describes how to build two very simple setups that will allow you to make both a laser transmission hologram and a white light reflection hologram. Both of these are "in-line" or "one-beam" setups, which are the least susceptible to vibration. For the laser transmission setup you will need the microscope objective we used to expand the beam in the Michaelson Interferometer, a 4″x5″ plate holder and a small or several very small highly reflective and stable objects to make a hologram of. This time place the objective a few inches away from the laser and allow the expanded light beam to travel the length of the big arm. At the far end of this axis we place the photographic film or plate holder with our object or objects on the same side as the laser and a few inches from the plate (no more than three inches to begin with). The idea is that the light will pass over the top of the object and form the reference beam while the rest of the light will strike the object, reflect off it onto the holographic plate and form the object beam. Because the two beams are in lines, there is very little possibility of their moving independently of one another: Greater stability is achieved.

Before continuing, I must go into more detail about the plate holder. Some of you may have 4″x5″ film holders that you may be able to modify to hold a 4″x5″ glass plate. These must be attached to the Big Beam so that they are firmly held in place. I cannot stress this enough. For those who do not have this kind of film holder a simple one can be made by making a U-shaped holder out of wood with a groove on the inside. The plate can be held firmly inside of this by using the metal springs used in picture frames to press the plate tightly against one side. Commercial plate holders are also available; these, of course, are more expensive but worth it. The holographic plate must, of course, be loaded in the dark, with the beam blocked off.

To make an exposure you will also need a shutter. The leaf shutters used on large-format cameras are ideal and should have the lens (if any) removed. They must be mounted securely. In a pinch it is possible to make an exposure by blocking the beam with a card and then lifting it manually. You time the exposure and gently put the card back in place. Before you do this you must let the whole system settle for at least 20 minutes before attempting to make an exposure. This allows all the components to come to rest and stabilize, maximizing your chances of success.

Holographic plates (glass base) are available from Agfa-Geveart and Kodak. I personally work with the Agfa plates. Film is also available, and once you become more proficient at making holograms, you can try sandwiching the film between two pieces of glass for stability in the plate holder. Film is much less expensive than holographic plates but less easy to handle. The Agfa emulsion used for recording with HeNe lasers is known as 8E75HD and is available either as cut film or glass plates. Exposure times will vary according to the reflectivity of your object, the spread of the lens and the power of the laser. Naturally the processing chemistry also affects the situation. To get started I would suggest processing your plate in Kodak D-19 for four minutes with continuous, gentle agitation, then washing the plate for 30 seconds in water and fixing it in Kodak fixer for four or five minutes. This should be followed with a wash of 15 minutes. The final rinse should contain a wetting agent such as Kodak Photoflo. The plate will take about 20 to 30 minutes to dry. Dry in a dust-free area. I would suggest that you begin by trying a 10-second exposure using the Agfa 8E75D emulsion. Then increase or decrease your exposure according to the density of your first recording. You should aim for a neutral density of 1.5 to 2.0. For those of you not used to evaluating neutral densities, you should see a dark pattern on the plate that is still transparent at a neutral density of 1.5. A neutral density of 4.0 is almost completely opaque.

With the dry hologram in hand we view it by placing it back in the plate holder in its original position but with the object removed. With the beam on we will see the holographic image behind the plate just as though it was really there.

By making a simple modification in our laser transmission setup, we can make a reflection hologram that we can see in white light (see Figure 3). This time the object is placed close to the plate but on the other side. We must expose and process the plate this time for a neutral density of around 3.0. In this case the reference beam is formed by the whole beam passing through the holographic plate and the object beam is formed by the light that reflects back off the object onto the plate. After processing and drying, the hologram can be best viewed by taking it outside on a sunny day and using the sun to illuminate it. These holograms reconstruct best with a good point source of light and can also be seen using lamps with quartz-halogen bulbs or projector-type bulbs. The low-voltage bulbs used in the Halo track system are particularly good. Ⓟ