

Building a Display Holography System

Introduction

White light display holograms are amazing images. They have unlimited visual depth and the ability to look around one object in the scene to see another object behind, also known as parallax. Holography is the only visual recording and playback process that can record three dimensional objects and scenes on an essentially two dimensional recording medium and playback these objects and scenes as a true three dimensional image to our unaided eyes. The image can be made to float in space behind, in front of, or straddling the recording medium, or all three. White light display holograms can be illuminated inexpensively with a white light source like a light bulb instead of having to use a laser.

Holography is one of the most significant discoveries made by humankind. Its discovery has had such a profound effect on our lives that the person who discovered the process in 1947, Dr. Dennis Gabor, received the Nobel Prize in Physics in 1971 for discovering holography.

There are many types of holograms, holography techniques, and applications, but this site deals exclusively with display holograms. White light display holograms are hung on a wall and are illuminated using a clear, halogen lamp. The following images are two of many white light reflection display holograms that hang on my laboratory walls.



In this section on Building a Display Holography System, I will take you step-by-step through building a versatile display holography recording system. In the section on Creating Transmission Holograms and Reflection Display Holograms, I will take you step-by-step through using the system to make two types of simple single-beam holograms, followed by making a multi-beam transmission hologram, and finally a multi-beam white light reflection display hologram.

I highly recommend that you print out a hardcopy of the two sections mentioned above and read completely through them before you start building your holography system and creating holograms. A hardcopy link for each section is provided in the web site's navigational menu.

You do not have to be a physicist or have knowledge of physics to accomplish these goals. All that is needed is the desire to build this system, a few simple mechanical skills, and the information on this site to guide you through creating the holograms. Although I have been producing holograms for over 40 years, I still get a feeling of awe and amazement every time I create a holographic image on my system. Everything I present on building a system and creating holograms on this site are tried and true. But this should not stop you from improvising. Just remember that stability during the hologram exposure is most important. For assistance in building this holography system, please contact Steve Michael (smichael@3dimagery.com).

Overview

Before you start building this display holography system and producing holograms, you need to see a visual overview of what a basic system (also known as an optical arrangement, optical setup or just setup) looks like when it is completely set up and ready to record a hologram. Figure 1a shows a photographic view of the system and Figure 1b shows a top-view illustration of the same system. Figure 1a shows the setup on a floor instead of on my optical table for clarity. This is a "multi-beam" transmission hologram setup because the laser beam is split into two beams by the beamsplitter instead of using just one beam without a beamsplitter for "single-beam" setups. The optical setups I will be describing on this site work extremely well. There are other systems that can be built (such as a sandbox system or screw-down system), but I have found my gravity system to be much more versatile for creating excellent holograms up to 12 inches x 16 inches (30.48 cm x 40.64 cm) in size. That's the objective of all this: to produce high quality white light reflection display holograms that can be hung on your wall and display their images.

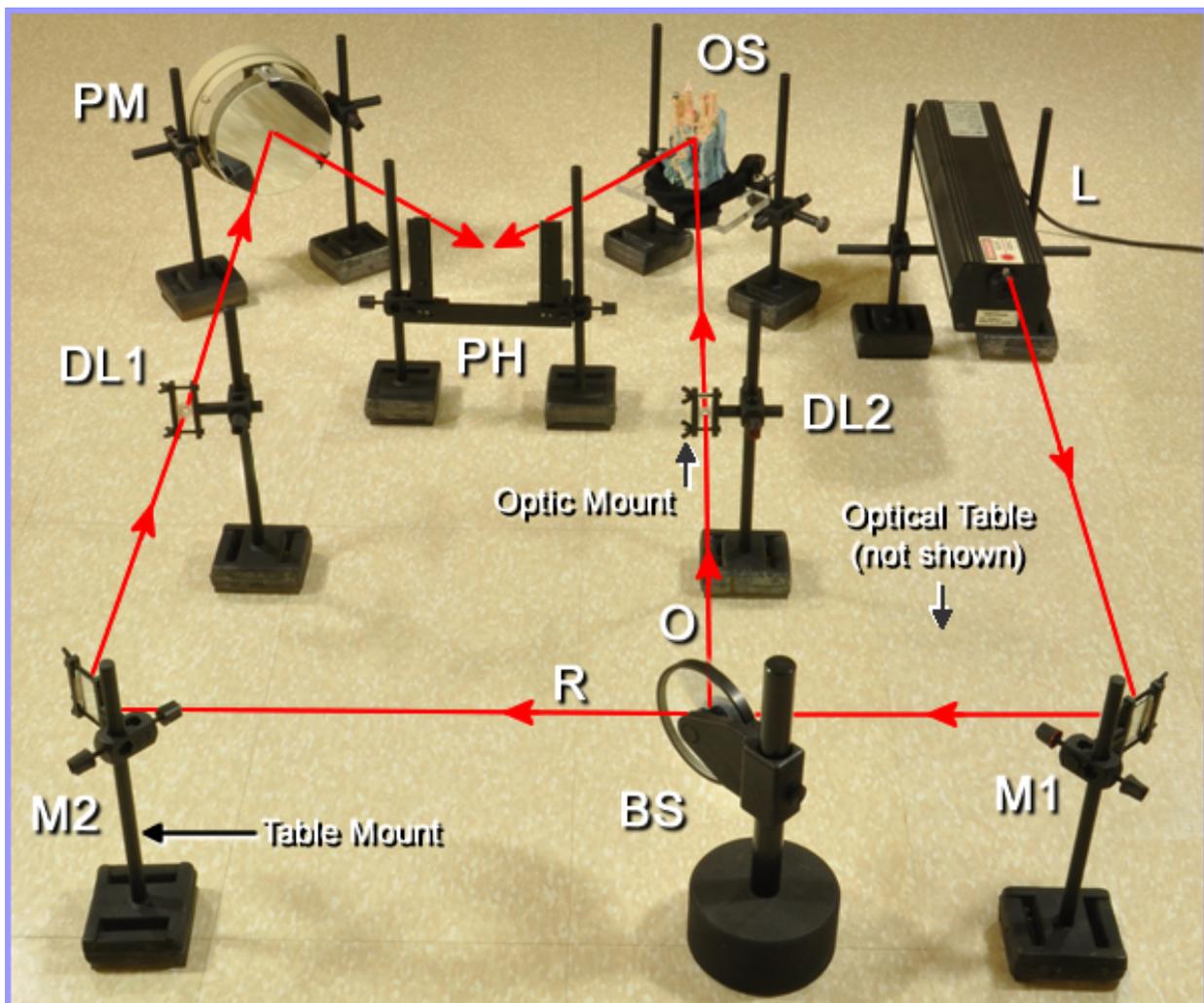


Figure 1a: Photograph of a basic multi-beam holography setup.

The setup shown in Figure 1a has five basic optical components. They are the laser (L), beamsplitter (BS), directional mirrors (M1 & M2), diverging lenses (DL1 & DL2), and the parabolic mirror (PM). In addition to the optical components, there are additional components which are the object scene (OS), the photographic plate/film holder (PH), the table mounts, the optic mounts, and the optical table. From this point forward, I will refer to the recording medium as a photographic plate or just plate and "film" will be inferred.

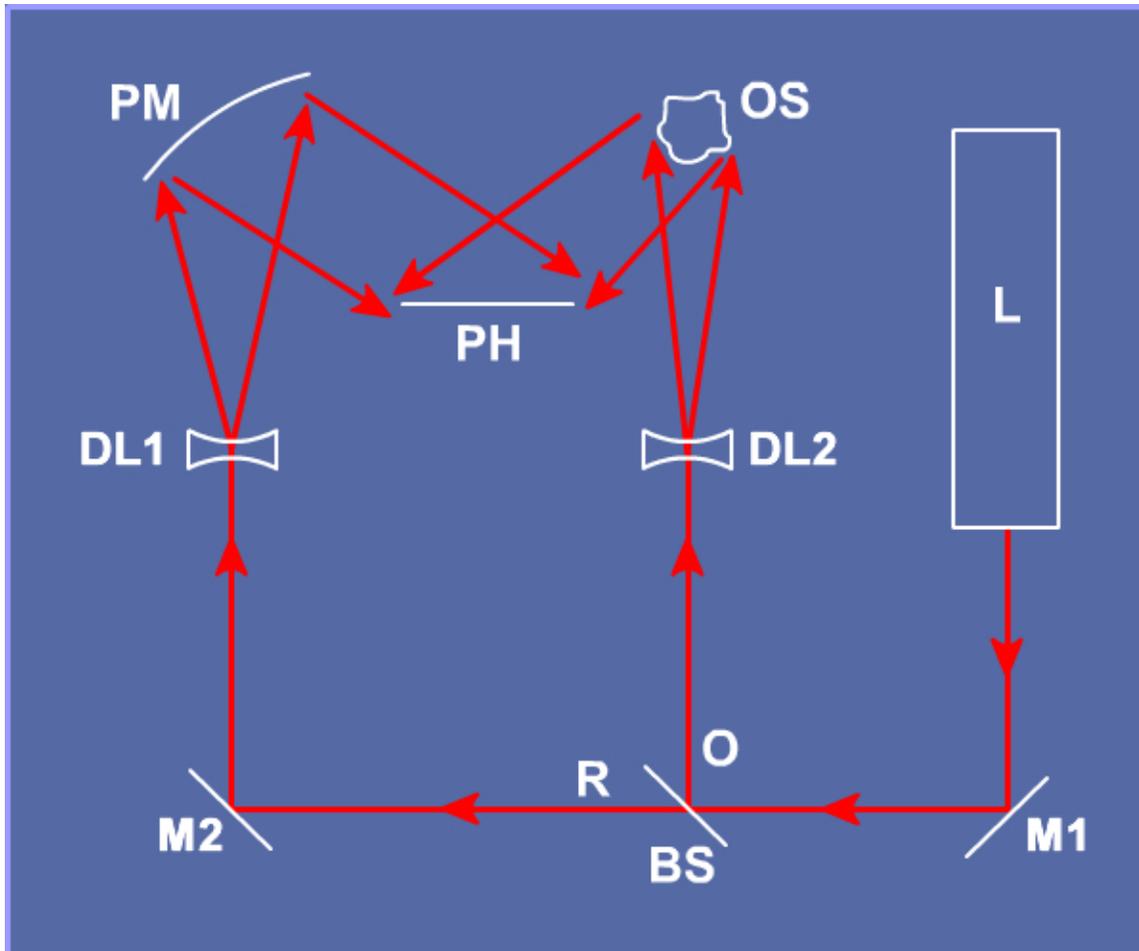


Figure 1b: illustration of a basic multi-beam holography setup (top view).

Referring to the diagram in Figure 1b, here is what happens during the recording process. The laser beam from the laser (L) travels to the first directional mirror (M1) and is reflected to the beamsplitter (BS). At the beamsplitter, the beam is split into two beams. These two beams are given names. One is the reference beam (R) and the other is the object beam (O). The reference beam (R) travels through the beamsplitter to a second directional mirror (M2) and is reflected to a diverging lens (DL1) that spreads the beam to a parabolic mirror (PM) that reflects the spread beam to the recording plate (PH).

At the same time, the reflected object beam (O) from the beamsplitter travels through a diverging lens (DL2) that spreads the beam and illuminates the three dimensional object scene (OS) which then reflects the beam's light to the recording plate (PH). The interaction (interference) of the light from the reference beam and the object scene's reflected light at the recording plate creates a holographic interference pattern within the recording plate at the microscopic level.

After the plate is chemically processed, it is placed back in the plate holder with its original orientation. The object is removed, or masked using black mounting board, and the reference beam is allowed to illuminate the recorded plate. Looking through the plate from the opposite side that the reference beam is illuminating the plate, you can see a three dimensional image of the original object scene suspended in space as if the original

object scene were still there. This illumination of the recorded hologram with the reference beam only is called reconstruction.

This optical setup is called a "transmission" hologram setup because both the reference beam and the reflected object light impinge on the plate on the same side of the plate. A "reflection" hologram has the reference beam impinging on the opposite side of the plate from which the object light is impinging.

The setup of the components shown in Figure 1a is a simplistic setup for illustrating the recording process. Your setup will be slightly different to facilitate creating high quality display holograms. In this section on Building a Display Holography System, I will cover:

- the optical table
- the recording environment
- the laser and its required properties
- beamsplitters
- mirrors and lenses
- building the table mounts
- building the optic mounts
- building the plate/film holder
- building a 3D object scene

I have provided supply houses and item costs in the Resources section located in the web site's navigational menu. I often review this area to make sure the information is current. If you find a broken link or the cost of an item has changed, please send me an e-mail (smichael@3dimagery.com).

Optical Table

The function of the optical table is to provide a vibration-free environment on its surface from ground vibrations and a substrate for the table mounts that support the components. I will cover more on vibrations later on this site. There are many commercially available optical tables but they are very expensive. Figure 2 shows a less expensive table that I've used in the past, but no longer.

The table in Figure 2 is 3 feet x 4 feet (91.44 cm by 121.94 cm) and is fine for making 2.5 inch x 2.5 inch (6.35 cm x 6.35 cm) holograms. You will need a table size of 4 feet x 6 feet (121.94 cm by 182.88 cm) for making 4 inch x 5 inch (10.16 cm x 12.7 cm) holograms and 8 inch x 10 inch (20.32 cm x 25.4 cm) holograms. A 5 foot x 8 foot (152.4 cm x 243.84 cm) table is needed to make 12 inch x 16 inch (30.48 cm x 40.64 cm) holograms. I recommend that you decide up front what maximum size hologram you will want to make in the future and buy the appropriate table size. This will save you significant money in the long run.

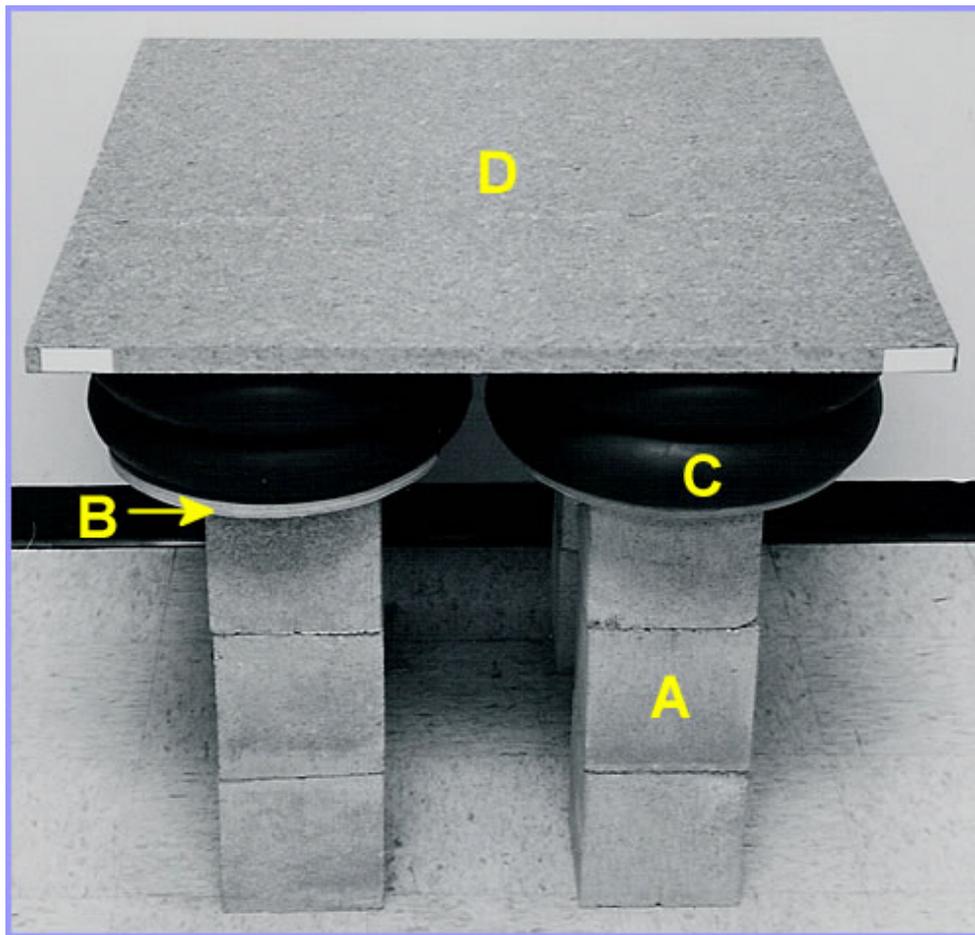


Figure 2: Granite optical table showing cinder blocks (A), plywood (B), inner tubes (C), and granite table (D).

The Table Legs

The following instructions apply to all table sizes even though the example is for a 3 foot x 4 foot (91.44 cm by 121.94 cm) table. The table will need to have four legs. Each leg is made from three cinder blocks, 8 inches (20.32 cm) on a side, stacked on top of each other, 3 blocks high. Their location under the table surface is important for providing the maximum dampening effect on ground vibrations.

- You should first draw the outer edges of your table surface on the floor with chalk or masking tape to help determine where the legs should be placed.
- A leg is placed at each corner of the table, just inside the width and length of the table.
- The center of the leg should be a distance of 22% of the width and length of the table from each corner of the table.
- For a 3 foot x 4 foot (91.44 cm by 121.94 cm) table, the center point, of a cinder block, for the width (3 feet) would be 7.92 inches (20.12 cm) from the edge of the table and the center point for the length (4 feet) would be 10.56 inches (26.82 cm) from the edge of the table.
- The diagonal distance from the corner to the center point of the cinder block would be 13.2 inches (33.53 cm) (Pythagorean equation: square root of 7.92" squared plus 10.56" squared: [$\sqrt{(7.92^2 + 10.56^2)}$]).
- This distance of 22% has been experimentally shown to be the optimal distance for maximum dampening by Newport Research Corporation which produces commercial optical tables.

The Plywood

On the top of each cinder block stack, place a circular piece of plywood 16 inches (40.64 cm) in diameter and 3/4 inches (1.9 cm) thick. These provide support for the inner tubes.

The Inner Tubes

On top of each piece of plywood, place two inflated inner tubes that have an approximate diameter of 15 inches (38.1 cm) when inflated. The inflation pressure or psi (pounds per square inch) cannot be measured with a tire gauge since the pressure is too low, but a good indication of proper inflation is being able to push your finger into the tube about 1.0 inch (2.54 cm). If the tubes are over inflated, high frequency vibrations may be passed to the table surface from the ground. If the tubes are under inflated, low frequency vibrations may be passed. The proper inflation is not all that critical, so don't lose sleep over it. Valve extensions can be connected to each inner tube valve to allow periodic inflation or deflation, or you can do what I do: have someone lift the corner of the table while you remove the tube, adjust the air pressure with an air pump, and re-insert it. Make sure nothing falls off the table while doing this! Better yet, remove all components from the table before removing a tube.

The Granite/Marble Slab

The final step for the table is to place a granite or marble slab, polished on one side, on top of the inner tubes, polished side up. This slab acts as the table surface and should have dimensions of at least 3 feet by 4 feet (91.44 cm by 121.94 cm), and be a minimum of 3/4 inches (1.9 cm) to 1.0 inch (2.54 cm) thick. A slab of marble or granite this size is very heavy (about 200 pounds [91 kilograms]) and will require four people to lift it. A heavy table is necessary to help dampen ground vibrations. Sometimes a slab that is slightly chipped, or a slightly smaller or larger remnant slab, can be found and purchased cheaper. Substitutions for the marble/granite slab are laboratory table tops or a piece of glass (at least 1/2 inch thick [1.27 cm thick] and edge-polished). I do not recommend using wood since it is flexible and not rigid (unless you are going to use sand box system). I presently use a 5 foot by 8 foot by 1/2 inch thick (152.4 cm by 243.84 cm by 1.27cm thick) glass table where I've created holograms up to 12 inches by 16 inches (30.48 cm by 40.64 cm).

Environment

The room where the optical table is to be located should be on the ground floor of your home or in your basement. This allows the earth to dampen all or most ground vibrations caused by movement in adjacent rooms or nearby vehicular traffic. It is essential that no ground vibrations reach the table surface during the exposure of the hologram. The optical table discussed previously will dampen ground vibrations nicely. In the section on Creating Transmission Holograms and Reflection Display Holograms, I will show you how to set up a Michelson interferometer to visualize these potential vibrations as well as other types of movements that can affect your exposure.

The optical table must also be located in a room that can be totally darkened. The reason for this is that when you are ready to expose a hologram, you will be placing a photographic plate in a plate holder (without light-protection) on the optical table and no light other than that from the laser, during the exposure, should impinge on the plate. Your plate processing area must also be in a room that can be totally darkened. Hopefully, your processing area can be in the same room as the optical table or adjacent to it (preferable). The processing area can also be anywhere in your house or the building you're working. The exposed plate can be carried to the processing area in a light-proof box or envelope.

The room in which the optical table is housed should be large enough to accommodate an optical table at least 3 feet by 4 feet (91.44 cm by 121.94 cm) with a minimum of 2.5 feet (76.2 cm) of walking space around the table on three sides. If you can manage this on four sides, that's even better. Also needed is shelving or cupboard space to house photographic plates, optics, optical mounts, and other related items.

If the room is air conditioned by a single air conditioning unit, the unit will need to be turned off at least 30 minutes prior to the exposure. If the room is air conditioned or heated by a central home unit, it will need to be turned off by a thermostat at least 30 minutes prior to the exposure. If you can't turn off the central air conditioning or heating system, such as in a large building, and there's an input vent to the room, you will need to physically block the input vent. Any airflow over or around the optical table will cause the optical components to move during the exposure and destroy the holographic recording. Specifically, the movement of certain components, during the exposure, of more than one-half of the laser light's wavelength, will destroy the image.

The optical table room should be kept clean and no smoking should be allowed. Smoke-related pollutants will eventually build up on optical surfaces and cause distortion and attenuation (absorption) of the laser beam.

Laser

You must use a laser to make a high quality hologram as shown in Figures 3a and 3b. A laser is a source of coherent light necessary to produce a high quality hologram. Fully coherent light sources, such as lasers, are both spatially coherent and temporally coherent. A laser emits light in a very narrow beam and is considered a point source (spatially coherent), as opposed to an extended source (spatially incoherent) such as a frosted incandescent bulb or a fluorescent lamp. A laser also emits light of a single color or wavelength (temporally coherent) whereas an incandescent light bulb or fluorescent lamp emits light of many wavelengths (temporally incoherent).



Figure 3a: Five milliwatt Helium-Neon laser.



Figure 3b: Table mounts for the laser.

There are four properties of a laser you need to consider when purchasing a laser for making holograms:

- the laser's power output
- the laser's beam polarization
- the laser's beam TEM mode
- the laser's beam wavelength

Laser's Power Output

I recommend you start your holography experience using a helium-neon (He-Ne), 5.0 milliwatt (mW) gas laser as shown in Figure 3a if you're starting with a 4 inch x 5 inch (10.16 cm x 12.7 cm) recording plate or smaller. You need to use at least a 5.0 mW laser to keep your exposure times short and reduce the potential of table vibrations, and/or component movements, destroying the image. The important message here is that the higher the power output of the laser, the shorter the exposure time. My exposures range from 10 seconds to 60 seconds, depending on the reflectivity and size of the object scene, the optical arrangement I'm using, and the recording plate sensitivity.

If you want to create 8 inch x 10 inch (20.32 cm x 25.4 cm) or 12 inch x 16 inch (30.48 cm x 40.64 cm) holograms, you will need at least a 20 mW or 35 mW laser, respectively. On the other hand, you could start with 2.5 inch x 2.5 inch (6.35 cm x 6.35 cm) recording plates which will further reduce your exposure time and cost using a 5 mW laser.

Laser's Beam Polarization

The laser should be linearly polarized as opposed to randomly polarized. A linearly polarized beam means that the electric and magnetic fields of the beam spend all of their time orientated in one direction perpendicular to the propagating beam direction and the two fields are at right angles to each other. A randomly polarized beam means these fields are continually rotating perpendicular around the propagating beam direction. When the beam is linearly polarized and two of these beams (from the same laser) interfere at the hologram, the energy in the electric fields add together in a maximum way and you get the highest image brightness and contrast in the recorded interference pattern. With a randomly polarized beam, it's a hit and miss affair and maximum brightness and contrast in the recorded patterns is usually not obtained.

Laser's TEM Mode

The TEM mode (transverse electromagnetic mode) should be single mode as opposed to multimode. The single mode designation is TEM₀₀. Multimode designations are TEM₀₁, TEM₀₂, etc. I'm not going to explain what TEM₀₀ means since it would be too lengthy to explain. You just need to make sure the laser manufacturer's specifications designate this mode.

Laser's Beam Wavelength

Most He-Ne lasers emit light at 632.8 nanometers (red) although they are available with infrared, yellow, orange, and green wavelengths. You should purchase a He-Ne with a 632.8 nanometers output because the recording plate sensitivity is set to this wavelength (red sensitive plates and films). Additionally, this red wavelength gives the highest power output from a He-Ne laser.

Regardless of what laser company you purchase from, their brochures (or web sites) will list the specifications for power output, polarization, TEM mode, and wavelength. He-Ne lasers are air cooled, operate on 110-120 VAC (volts alternating current), and have a life expectancy of greater than 20,000 hours.

Additional Information

Laser Safety

Never let an **undiverged** He-Ne laser beam hit your eye. It may severely damage your retina and your sight. It could possibly blind you. It really hurts too. I know. When I say "undiverged" beam, I mean the beam coming

directly out of the laser, which is about 0.08 inches (0.2 cm) in diameter and at full power. Once the beam gets spread out using a diverging lens, then it's relatively safe (for a 5.0 mW to 50 mW He-Ne laser). This web site and its author are in no way liable for your use of any laser.

Coherence Length

A fifth property of a laser is the coherence length of a laser beam. This is also known as the depth-of-field zone. Manufacturers usually do not specify the coherence length of He-Ne lasers. This property determines how deep your object scene can be before the illumination of the object scene in the recorded hologram starts to fall off to zero. If the depth of your object scene is greater than the coherence length of the laser beam, those areas outside your depth-of-field zone in your object scene will look illuminated on the table, but the hologram will not record these areas. That is why when you measure your optical path lengths, to be discussed later, you should always measure to the center of your object scene. Imagine the depth-of-field zone as a circle with a diameter of 10 inches (25.4 cm) with the circle's center located at the center of your object scene. Any part of your scene outside this diameter will not be recorded.

As an example, a 5 mW He-Ne laser's coherence length is around 10 inches (25.4 cm). So if your object scene is 10 inches (25.4 cm) wide and 20 inches (50.8 cm) deep and you've measured to the center of the object scene, then 5 inches (12.7 cm) in front of, and behind, that center point will be recorded in the hologram. The rest of the object scene will be dark and not visible.

Beamsplitter

Single-beam hologram optical setups do not require a beamsplitter, but multi-beam setups do and are a critical optical component of the system. A beamsplitter has three important functions:

- To split the beam from the laser into two beams (reference and object beams)
- To control the individual intensities of each of the two beams
- To set the initial directions for each of the two beams

There exists an important intensity relationship between the reference (R) and object (O) beams at the photographic plate in a multi-beam setup. This is called the beam intensity ratio (R/O). The intensity of the reference beam must always be greater than the intensity of any reflected point from the object scene to the plate. Just before you make a multi-beam hologram exposure in the section on Creating Transmission Holograms & Reflection Display Holograms, you will need to adjust the beam intensities of the reference and object beams. The ability to adjust the intensity between the two beams, without changing the directions of the reflected and transmitted beams from their original preset directions, is easily achieved using a variable beamsplitter. I will cover this ratio adjustment in more detail later when you set up for your first multi-beam transmission hologram.

Linear-gradient Variable Beamsplitter

You should try to use a variable beamsplitter. Most are priced reasonably and will make your experience creating multi-beam holograms easier. The least expensive variable beamsplitter you can use is a linear-gradient variable beamsplitter shown in Figure 4a.



Figure 4a: Linear-gradient variable beamsplitter.

This beamsplitter allows you to slide the beamsplitter through the beam and change the intensities of the two beams while maintaining the preset directions of the reflected and transmitted beams as the intensities are adjusted. This beamsplitter can be mounted a couple ways:

1. You can use the optic mount shown in Figure 4b. Building this optic mount is covered under Optic Mounts. The optic mount with the beamsplitter is attached to a table mount and you adjust the beam ratios by sliding the table mount carefully on the optical table surface.

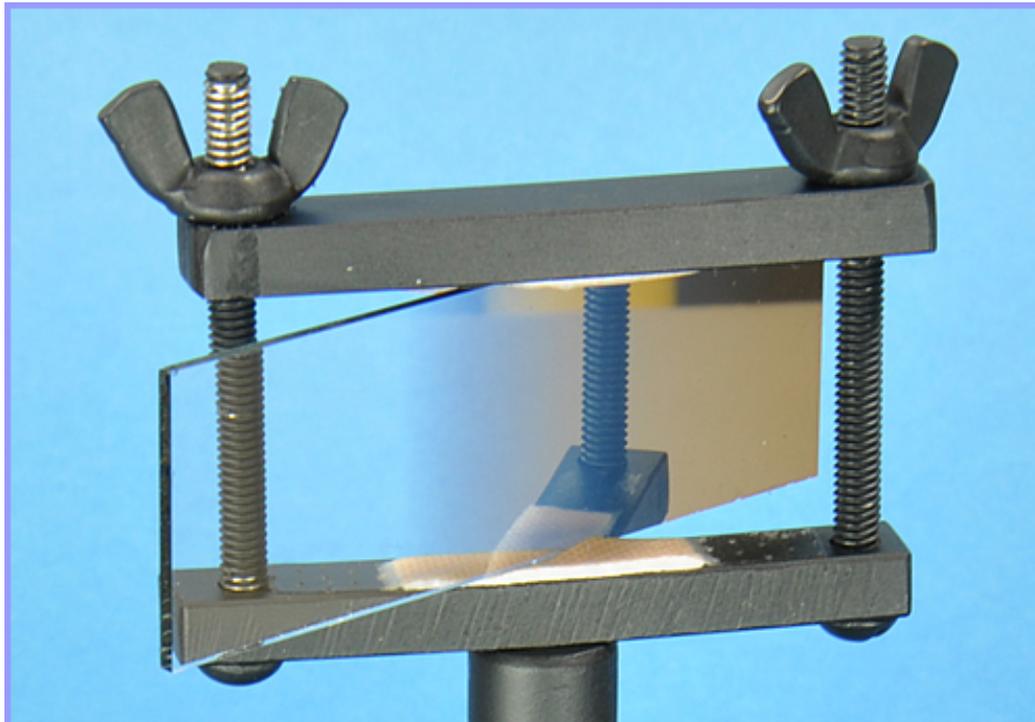


Figure 4b: Optic mount for linear-gradient variable beamsplitter.

If you need more precise movement when using this mounting method to adjust the beam ratios, you can use a single axis translation stage like the one shown in Figure 4c. You can smoothly turn the knob and move the beamsplitter in small increments along the rack and pinion track.



Figure 4c: Translation stage.

2. Alternatively, you can mount this beamsplitter in a special mount available from Edmund Optics shown in Figure 4d.

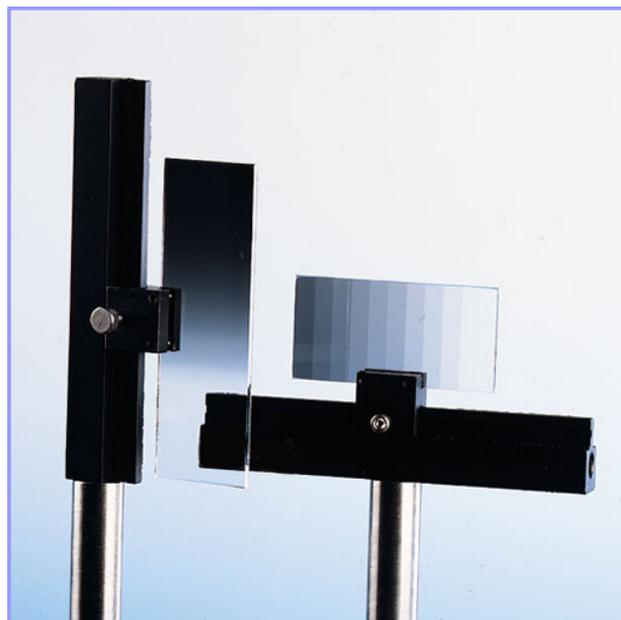


Figure 4d: Adjustable linear beamsplitter mount.
(photo courtesy of Edmund Optics)

This beamsplitter mount allows more precise movement by using two set screws, which when loosened, allows you to slide the beamsplitter mount along a smooth groove and then re-tighten the set screws.

Circular-gradient Variable Beamsplitter

The best type of beamsplitter, and the easiest to use, is called a circular-gradient variable beamsplitter shown in Figure 4e. A circular-gradient variable beamsplitter has a wheel with an aluminum reflectivity gradient on one side of the wheel to control the amount of laser light reflected and transmitted (the laser beam should impinge on the gradient side of the beamsplitter). As the wheel is rotated from 0 to 360 degrees, the intensity of the reflected beam is decreased while the intensity of the transmitted beam is increased. You can choose either the reflected beam or the transmitted beam as the reference (R) beam. The other beam will then become the object (O) beam. Referring again to Figures 1a and 1b, the transmitted beam (R) is the reference beam in that basic setup.

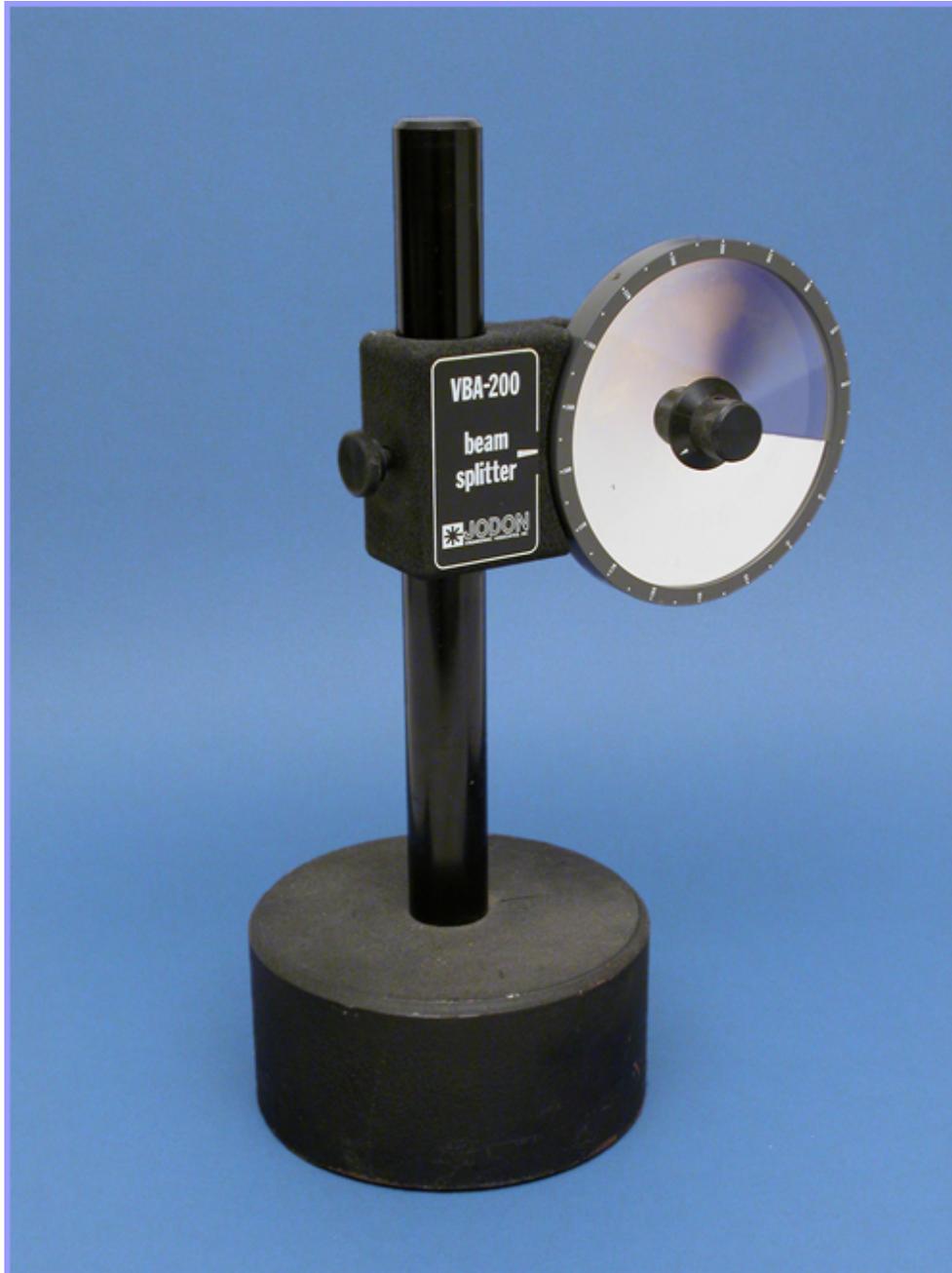


Figure 4e: Circular-gradient variable beamsplitter.

Other Types of Beamsplitters

There are many other types of beamsplitters such as plate, cube, prism, and pellicle beamsplitters just to mention a few. Of the four mentioned, the plate beamsplitters have set ratios of reflection and transmission. This means that if you want to change the ratio, you need to insert a different plate beamsplitter with that ratio. This requires you to have several of these plate beamsplitters, each with different ratios. Additionally, you are limited to how precisely you can adjust your beam ratio because of the limited number of different ratios available.

The remaining three types mentioned only allow you to change the ratio by changing the incident angle of the beam. This in turn changes both the reflected and transmitted beams' directions causing you to realign components downstream of the beamsplitter. I don't recommend you using any of these four beamsplitters. I just wanted you to know about them.

Mirrors and Lenses

Directional Mirrors

The directional mirror shown in Figure 5 is a front-surface enhanced-aluminized mirror that is used to direct the reference and object beams to various locations on the optical table. Because of the small 0.08 inch (0.2 cm) diameter of the laser beam, I purchase small mirrors about 1 inch x 1 inch x 1/8 inch thick (2.54 cm x 2.54 cm x 0.3 cm thick) in size to direct the beam around the table. In some setups, though, you'll need larger mirrors that are placed in the beam(s) beyond the diverging lens.



Figure 5: Directional mirror in optical mount.

Diverging Lenses

The function of a diverging lens, shown in Figure 6a, is to spread (diverge) the small diameter of the laser beam into a wider diameter beam so that the photographic plate and object scene are uniformly illuminated. A diverging lens can be a simple double-concave lens as shown in Figure 6a, or it can be a more complex optical component such as a microscope objective as shown in Figure 6b and mounted in the optic mount shown in Figure 6c. Or the microscope objective can be used in conjunction with an optical device called a spatial filter shown in Figure 6d.

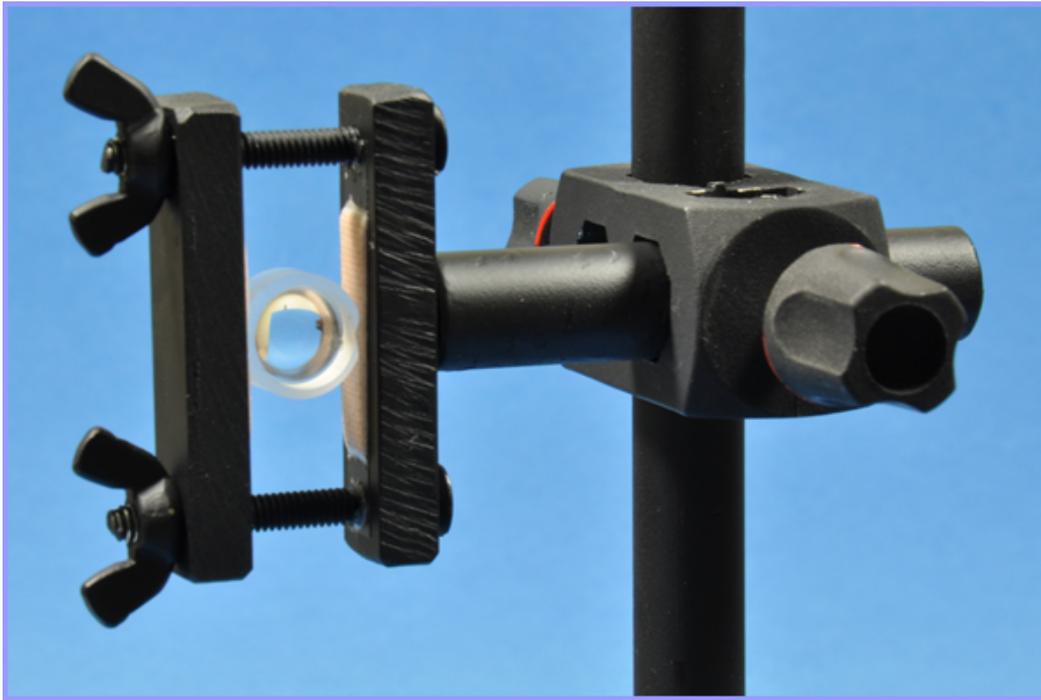


Figure 6a: Double-concave diverging lens in an optic mount.



Figure 6b: Microscope objectives with different magnifications.



Figure 6c: Microscope objective mounted in optic mount.

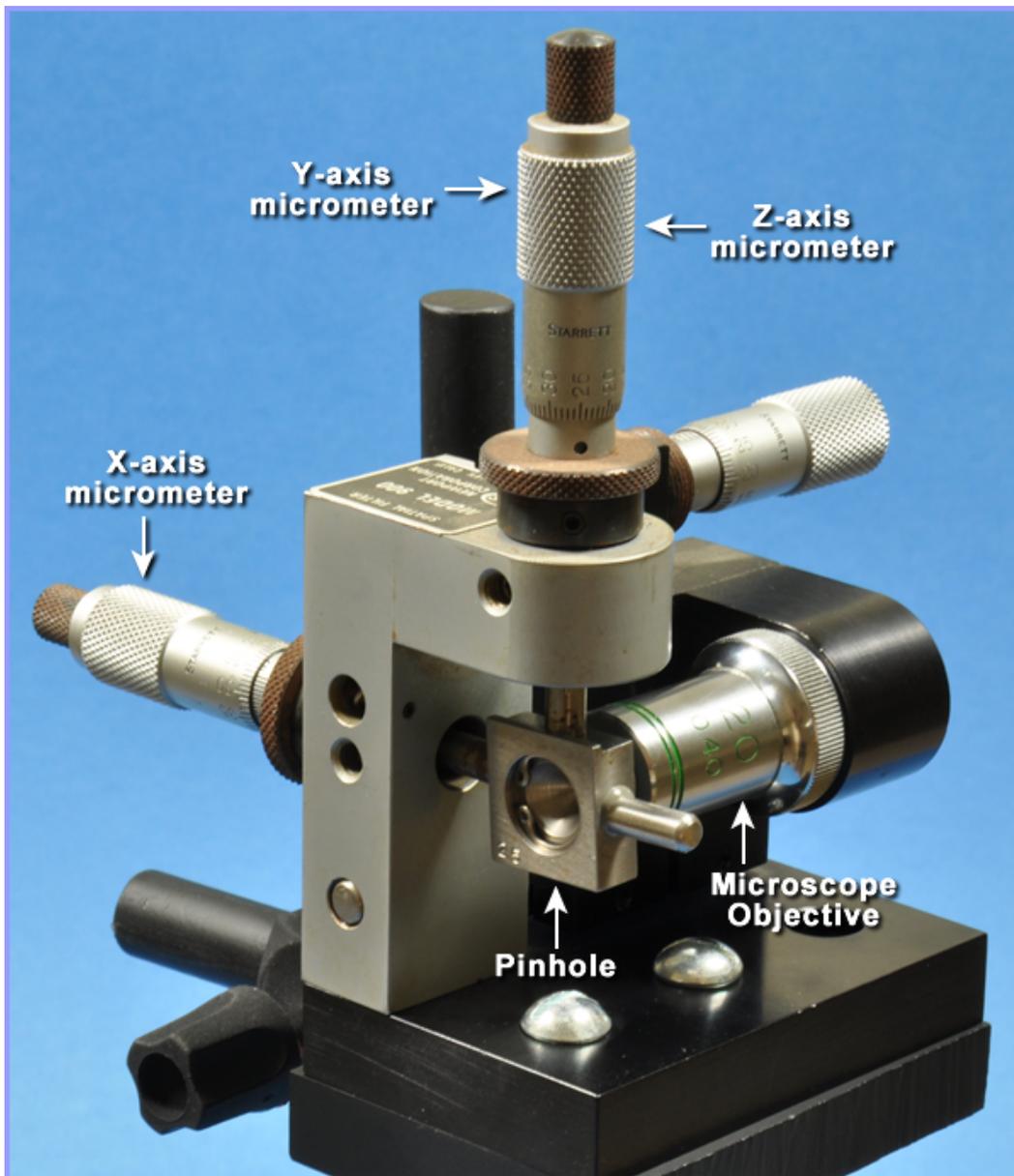


Figure 6d: Spatial filter.

A simple double-concave lens will work fine as your first diverging lenses and they are the least expensive. Lenses of this type can be difficult to use if their diameters are less than -9 mm, though not impossible. This lens should be kept clean, scratch free, and handled only by its edges. All the optical components (beamsplitter, directional mirrors, diverging lenses, and parabolic mirror) must be clean and free from scratches to produce an artifact-free, high-quality hologram. All of the optics shown here can be gently cleaned with cotton swabs and acetone to remove dust and fingerprints. Photographic lens paper can also be used. The best way to clean your optics is to wrap the cotton tip of a swab with a couple layers of photographic lens paper and hold the lens paper in place on the swab shaft with a twisty. Then dip the lens paper covered cotton tip into the acetone, shake off the excess acetone (away from another objects), and gently clean the optic stroking in one direction. Constructing the mounts for a lens, microscope objective, or spatial filter is discussed in the section under Optic Mounts.

If you can afford a spatial filter or two, get them. Spatial filters have three functions. The first is to diverge the laser beam as a simple double-concave lens or microscope objective does. The second is to eliminate the recording of scattered noise (artifact noise) on the hologram plate caused by dust and scratches on the optics. The last function is to partially eliminate internal noise created in the laser cavity that travels along with the beam (a spatial filter cannot totally eliminate internal laser cavity noise. Later, I will show you how to use a cardboard mask to completely block this noise whether you're using a simple lens, a microscope objective, or a spatial filter). Using a spatial filter will provide the ultimate in a totally clean holographic image pretty much irrelevant of scratches, dust, or fingerprints.

A spatial filter is comprised of three micrometers (X, Y, Z), a microscope objective, and a pinhole as shown in Figure 6d. The X and Y micrometers move the pinhole to center on the microscope objective's central light axis, and the Z micrometer moves the microscope objective forward and backward so that the narrowest point of the objective's focal point is located at the center of the pinhole. When both these conditions are achieved, you have a very clean beam at the plate for the reference beam. Having a clean beam for the reference beam is more important than having a clean beam for the object scene, but you should strive for a clean object beam also. Placing a piece of white cardboard in the plate holder, Figure 6e shows what the beam may look like without a spatial filter and its pinhole. Figure 6f shows what the beam would look like using a spatial filter and its pinhole or having a clean lens to start with.

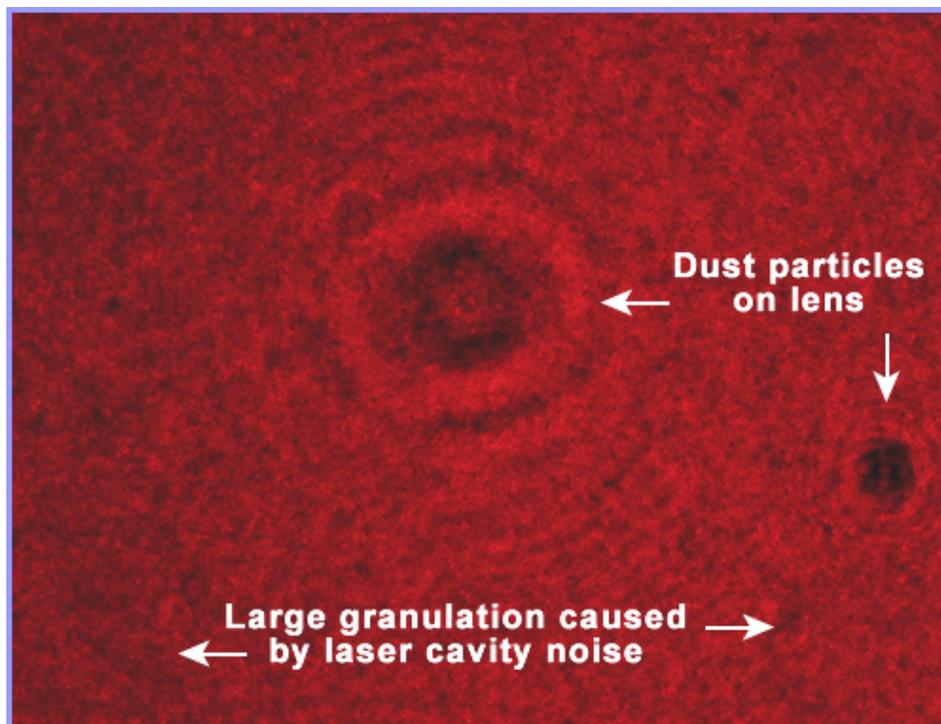


Figure 6e: Laser beam without spatial filter and pinhole.



Figure 6f: Laser beam with spatial filter and pinhole.

Spatial filters are expensive. You need not consider these for your first holograms, either single-beam or multi-beam. When you are setting up an optical setup, you can start with a -15 mm focal length, simple, double-concave lens or an approximately equivalent 10x microscope objective for your diverging lenses. Depending on your optical setup, down the road you may want to have handy a range of microscope objectives (5x, 10x, 20x, 40x) or an equivalent range of double-concave lenses (-25 mm, -15 mm, -9 mm, -4.5 mm respectively) to allow you more versatility in how wide you can spread the beam over a certain distance. A 40x microscope objective spreads a beam wider over the same distance than a 5x objective. But as I mentioned above, start with a -15 mm focal length, simple, double-concave lens (or 10x microscope objective). Later, I will provide you with a simple equation that will tell you how far a diverging lens, with a certain focal length, needs to be from the object scene and plate holder to provide uniform illumination.

Parabolic Mirror

The function of the parabolic mirror, shown in Figure 7a, is to collimate (make parallel or flat) the diverging reference beam's wave front used in the multi-beam transmission hologram so that the holographic image has a magnification of 1x. This magnification factor is very important because we will use a transmission hologram's real image to create a reflection display hologram that can be viewed with white light instead of laser light and any magnification in transmission hologram's real image will distort the reflection display hologram's image. I will be covering this in more detail in the section on Creating Transmission Holograms and Reflection Display Holograms.

Let me take a moment here to further clarify the term collimate. Since you have to diverge the reference beam with a diverging lens to make sure your plate is uniformly illuminated, this diverging beam has a curvature to it (called the wave front of the beam). This curvature introduces magnification into the holographic image unless it's not curved, but flat. The parabolic mirror flattens the wave front and eliminates the curvature, and in turn, eliminates any magnification so that the recorded holographic image size is the same size as the original object scene.



Figure 7a: Parabolic telescope mirror in its mount.



Figure 7b: Parabolic telescope mirror mount.

The parabolic mirror should have a diameter of 6 inches (15.24 cm) and a focal length of 24 inches (60.96 cm). This diameter will adequately cover a 4 inch x 5 inch (10.16 cm x 12.7 cm) plate and the focal length will be adequate for a 3 foot x 4 foot (91.44 cm by 121.92 cm) table.

If you can't afford this mirror, there is another method for eliminating magnification. In this method, you want to place the diverging lens in the reference beam at a distance from the plate holder at least 10 times the diagonal size of the plate. This will essentially give you a flat wave front at the plate. For example, if you're using a 4 inch x 5 inch (10.2 cm x 12.7 cm) plate, its diagonal size is 6.4 inches (16.26 cm). Therefore, the diverging lens should be placed at least 64 inches (162.56 cm) from the plate. This will also require one or

two additional larger directional mirrors to reach a length of 64 inches (16.26 cm) since your beam will be diverging. When we get into the actual optical setups, I will discuss both methods of collimating and the additional directional mirrors.

Table Mounts

Each optical and non-optical component of the hologram recording setup will need at least one table mount (Figure 8, parts A, B, & C). Some components, like the plate holder, will need two. This adds up to a minimum of 7 mounts for the simple single-beam hologram setup. The most complicated optical setup, in the section on Creating Transmission Holograms & Reflection Display Holograms, uses 20-24 mounts. If you feel you need to use more than one mount for a component where I've used only one, please feel free to do so. You can't have too much stability!

This holography system uses gravity and the mass of the lead weight to keep the table mounts stable and in place on the surface of the optical table. This type of mounting system allows precise positioning of components on the optical table. I've used many other types of mounting systems in the beginning years of making holograms such as screw-down mounts, magnetic mounts, and sand table PVC tube mounts, but the gravity/mass system is the best, easiest, and most versatile to use in my experience.

Table mounts are needed not only to hold, support, and stabilize various components but also to make sure the laser beam runs parallel to the table surface at a height of 9 inches (22.86 cm). I have found this height to be optimal in all of the optical setups on this web site, both in terms of component stability and in successfully positioning certain components above & below this height. This means that the output aperture of the laser is positioned at 9 inches (22.86 cm) above the table surface. More on this later.

Each table mount is made of a 5 pound (2.27 kilogram) lead diving weight (the lead provides the necessary mass stability) and a 13 inch (33 cm) long, 1/2 inch (1.27 cm) diameter, solid aluminum pole (Figure 8, parts A & B). To construct the mount, first take the lead weight and using a 9/16 inch (1.43 cm) bit, drill a hole in the center of the weight but not all the way through to the bottom. I use a piece of duct tape around the bit shaft to show where I need to stop. Make sure you drill as perpendicular to the weight as possible. If your drill has a level bubble, that would be most helpful. (Caution: diving weights are made of lead, so be sure to clean up all loose lead and working surfaces, and wash your hands afterwards.)

Note: Drilling the Holes

Start the hole with a small bit, such as a 1/8 inch (0.32 cm) bit, and work your way up to the required bit size using the bits sizes in between. By starting with a small bit, you can more accurately start the hole where it should be located and obtain a vertical hole. I mark the hole's position to be drilled with a permanent marker pen and then make an indentation at that mark using a small nail and hammer. This helps to keep the bit in the proper location when I start the drill. I also start the drill at a low RPM and then increase the RPM once the hole is started. Use this method for all drilling requirements that follow.

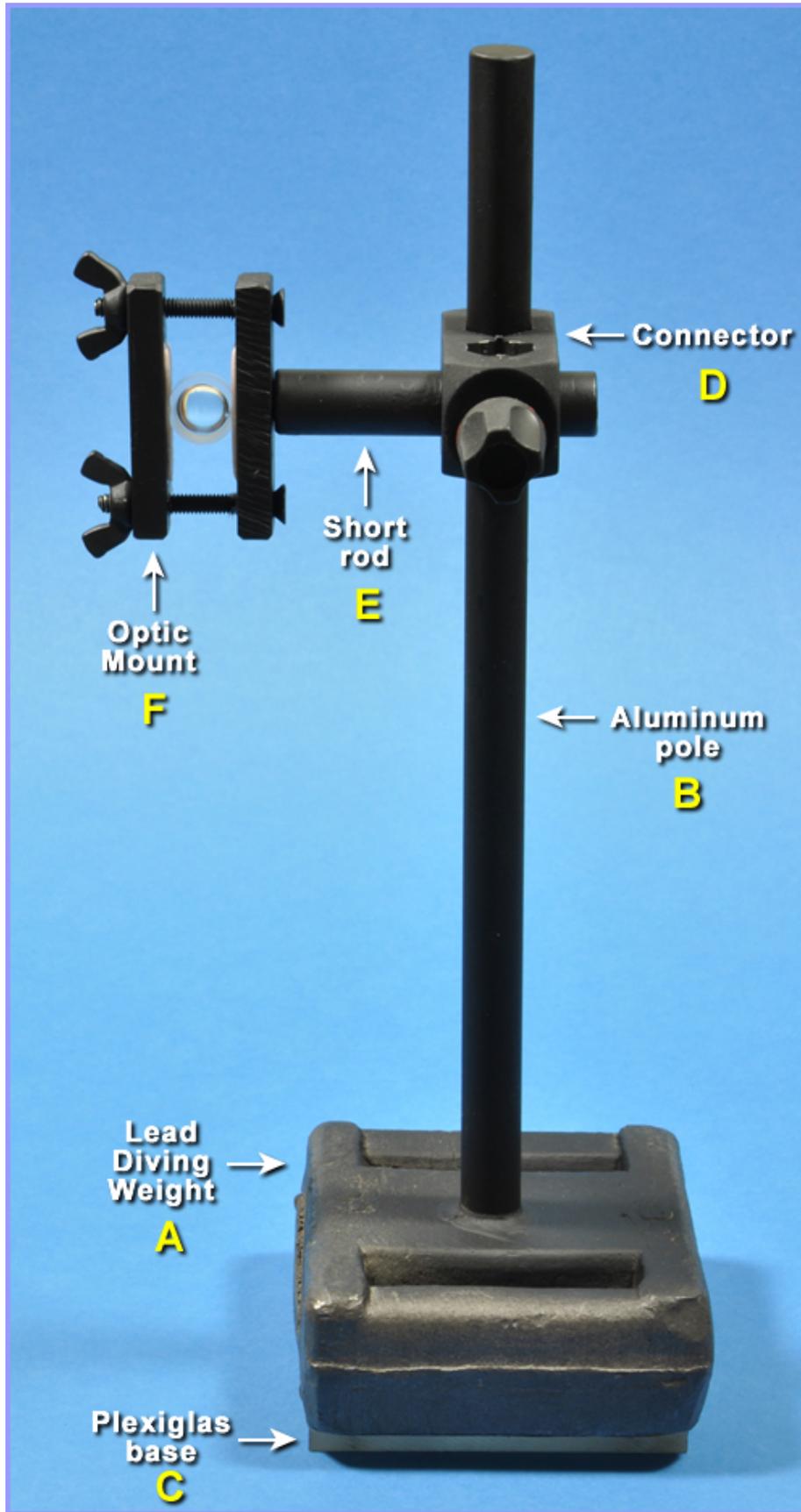


Figure 8: Table mount showing 5 pound (2.27 kg) lead diving weight (A), solid aluminum pole (B), Plexiglas base (C), connector (D), short rod (E), and optic mount (F).

Solid aluminum, 1/2 inch (1.27 cm) diameter poles are commercially available in 3 foot (91.44 cm) lengths at most hardware stores. I prefer aluminum over zinc because zinc is a softer metal. Each mount pole should be cut to a 13 inch (33 cm) length and the edges filed smoothly on the ends and beveled. Before you attach this pole to the lead weight, spray paint the pole with flat black paint. Rust-Oleum fast drying enamel spray paint works well. By painting the poles black, stray laser light will not reflect off the poles and, therefore, the poles will not be seen in your hologram. Unless you want to, you do not need to paint the lead weight because of its dark gray color. You can find lead weights shown in Figure 8 at diving shops. Make sure the weights are not covered with plastic and that the lead is solid, not hollow in any way except for the belt slots. Many mounting parts that follow will need to be painted flat black and you should allow the paint to dry 24 hours before using that painted item in the mount building steps.

Mix up a small amount of 5 minute epoxy glue and insert about a teaspoon into the lead weight hole. Next, insert the pole into the hole. It will be a tight fit and you may find that a pocket of air develops in the hole under the pole. Place the weight on the floor and hit the top end of the pole gently with a rubber mallet. The glue will gradually seep out around the pole and the pole will finally come to rest on the floor of the hole. If the pole has some play in the hole, you will need to hold the pole vertically until the glue starts to cure and harden. You can use a small level to help you determine how vertical the pole is. Wipe away any excess seepage glue with rubbing alcohol and a paper towel before it starts to cure.

Next, using 1/4 inch (0.64 cm) thick Plexiglas, cut a rectangle slightly smaller than the size of the lead weight's bottom. Make sure you remove any protective paper or plastic covering on both sides of the Plexiglas before you do the next step. Cement the Plexiglas with 5 minute epoxy to the base of the lead weight opposite the pole (Figure 8, part C). The Plexiglas provides an absolutely flat contact surface with the polished granite surface of the optical table, thus eliminating any rocking. The lead weights are not smooth on the bottom, and without the Plexiglas, they will not lay flat on the table and rocking may occur. This reduces the stability of your system.

Short Rod

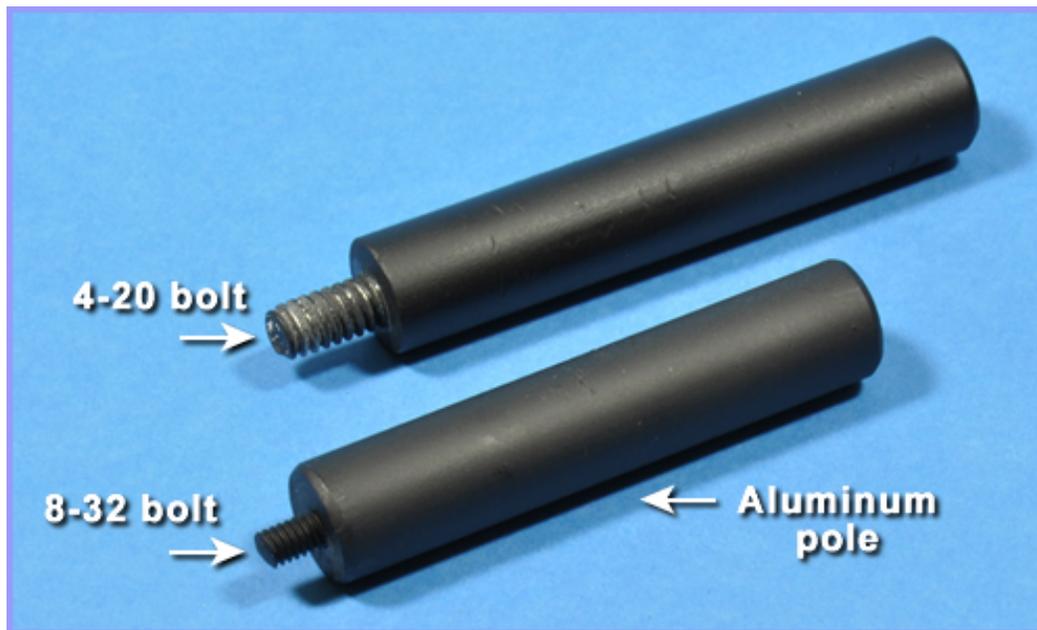


Figure 9: Short rod for attaching optic mount to table mount.

Each table mount will have a short rod (Figure 9 and Figure 8, part E) attached to it with a connector (Figure 8, part D). Some of these rods will have optical holders (Figure 8, part F) attached to them for the mirrors, diverging lenses, and the linear-gradient variable beamsplitter (if you're using one). Others will be used with the table mounts to mount the laser, parabolic mirror, plate holder, and object scene. You will need two different

types of short rods. One will need a 8-32 bolt and the other a 4-20 bolt. Each type of short rod will be used in different situations depending on what you are mounting to them. If you are using an optic mount for a small mirror, you will use the 8-32 rod. The telescope mount for the parabolic mirror will use a 4-20 rod because the mount and mirror are heavier.

The short rods need only be 3 inches (7.62 cm) long and are cut from the 1/2 inch (1.27 cm) diameter solid aluminum poles. After the rod is cut to length and the end edges filed smooth and beveled, place it vertically in a vise (use a level to make sure the rod is vertical). On the top center end of the rod, drill a hole about 1 inch deep with a 1/8 inch (0.32 cm) bit. Clean out the hole of any drilled debris by removing the rod from the vise, lightly tapping the end of the rod with the drilled hole against a table top to dislodge any debris, and replace the rod back in the vise vertically with the hole upward for the next step. As I mentioned previously, start your drilling with a small 1/16 inch (0.16 cm) bit and work up to the required size.

Next, with an 8-32 tap, make threads in the drilled hole with clockwise turns. Once you have got the tap started in the hole, use one clockwise turn, or less, at a time to minimize breaking the tap. Then reverse the direction about one turn, then continue forward with one turn again. Keep going forward and reversing until the threads are about 3/4 inch (1.9 cm) deep. As the threads are created, bits of aluminum will fall to the bottom of the hole and will need to be dumped out when you finish tapping the hole. Tapping a hole with threads takes some practice. I've had my share of broken taps in the hole and have had to start again using the other end of the rod. 8-32 taps are especially prone to breaking. So when you are creating the thread clockwise and you feel strong resistance, stop, back-off, and reverse direction (counterclockwise) about a full turn. Then continue clockwise again. This helps dislodge small pieces of aluminum that get stuck in the teeth of the tap.

Note: Always make sure the drill bit diameter is slightly smaller than the thread tap size diameter you're using. If the drill bit is too small, you'll have a heck of a time creating the threads. If the drill bit is too big, you won't get any threads. For a 8-32 tap, use a 1/8 inch (0.32 cm) bit. For a 4-20 tap, use a 3/16 inch (0.48 cm) bit.

After the hole is drilled and tapped, screw a 1.0 inch (2.54 cm) long, 8-32 bolt into the hole until it is tight. Take the rod and place it horizontally in a vise, and with a hacksaw, cut off the bolt head, leaving a 1/4 inch (0.64 cm) length of threads. With a file, smooth the end. With a fine file, clear the threads of any metal on the end. Test the thread functionality by screwing on a nut. You are now ready to add an optic mount (to be discussed in a moment) to the end of the rod. Spray paint the rod and bolt with enamel flat black paint.

Use the above method for creating a short rod having a 4-20 bolt. The bolt length for this size bolt should be 1/2 inch (1.27 cm) long instead of the 1/4 (0.64 cm) inch length because the 1/4-20 bolt will be used for heavier components.

Connectors

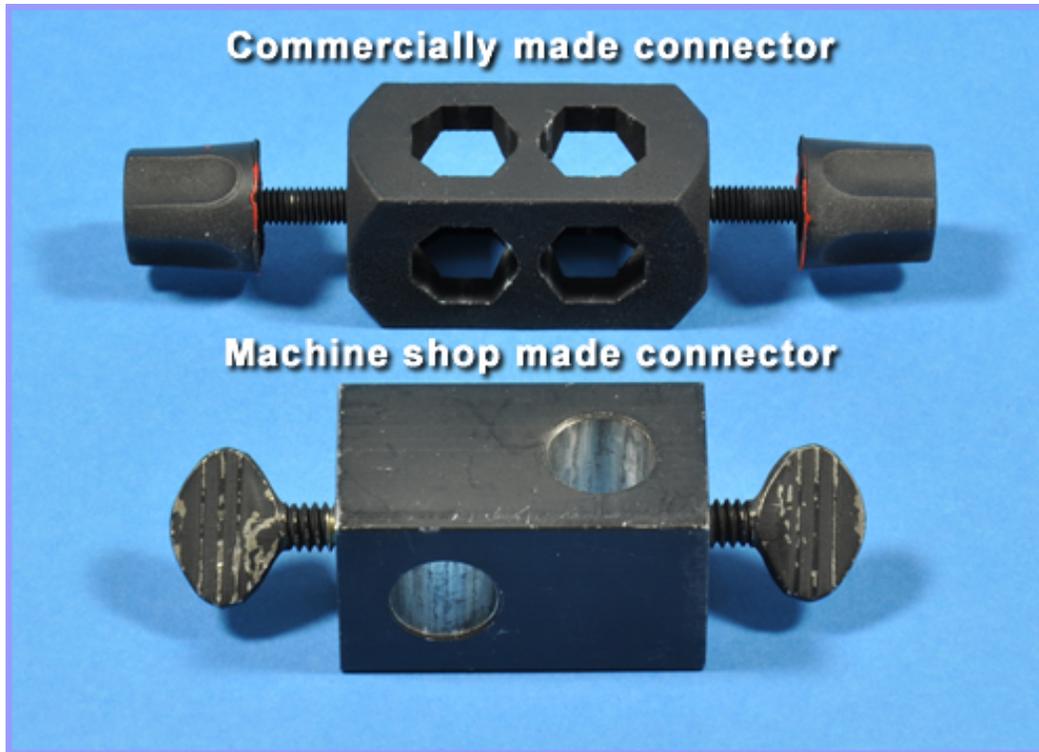


Figure 10: The top connector was purchased from a supply house. The bottom connector was made in a machine shop.

The connectors shown in Figure 10 used with all the table mounts and short rods can be purchased from supply houses or can be made using your own drill press or a machine shop can do them for you. Whichever approach you use, the connector holes should be able to accommodate the 1/2 inch (1.27 cm) diameter solid aluminum poles. If you plan to make them yourself, it is important that the holes be drilled exactly perpendicular to help maintain a right-angle alignment between the table mounts and rods.

If a machine shop makes them or you make them yourself, here is the method you should use. A solid piece of aluminum was used with the dimensions of 1-3/4 inches x 1 inch x 1 inch (4.45 cm x 2.54 cm x 2.54 cm). Two 5/8 inch (1.59 cm) diameter holes were drilled in the aluminum at right angles to one another, with the center of each hole 1/2 inch (1.27 cm) from each end. Poles and rods are clamped into the holes with 1/4-20 thumb screws on each end screwed into tapped 1/4-20 threads.

I prefer the commercially available clamps because there are multiple holes for the table mounts and short rods which provide more versatile ways to mount the rods. The solid aluminum poles fit very well in these connectors. Also the cost is the same for either type of connector. Whatever connector you use, spray paint the connectors and thumb screws with enamel flat black paint. A supply house for these commercial connectors is covered under Resources.

Optic Mounts

Beamsplitters, Mirrors, and Lenses

The homemade optic mount shown in Figure 11a can be used to mount your linear-gradient variable beamsplitter, small directional mirrors, and diverging lenses or microscope objectives (Figures 4b, 5, and 6a & 6c respectively). If you purchase a circular-gradient variable beamsplitter, a table mount will come with it or you can purchase one for it. Figure 11b shows the individual parts before painting.



Figure 11a: Optic mount.

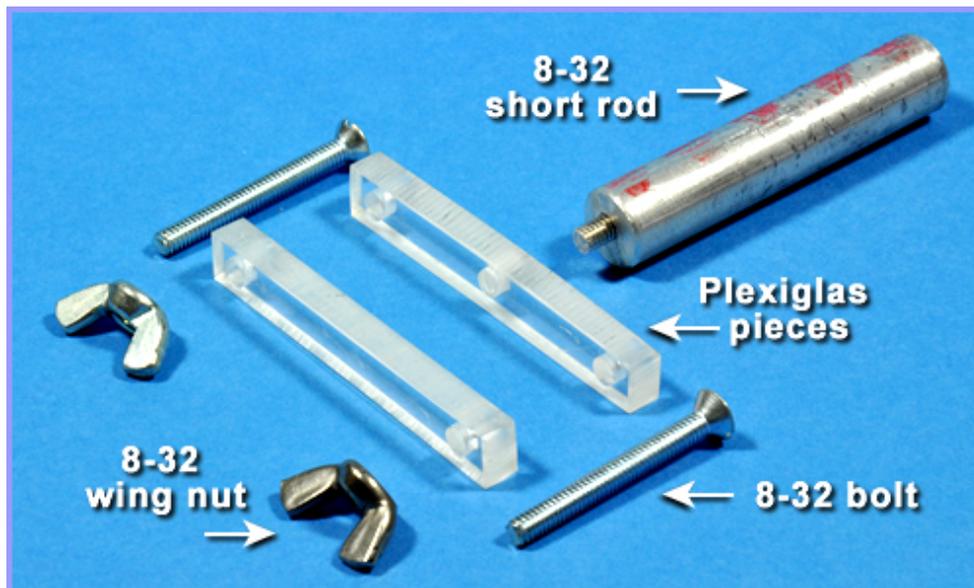


Figure 11b: Optic mount parts.

- Two pieces of Plexiglas are used to sandwich the optical component between them using two bolts with wing nuts.
- The two Plexiglas pieces are 3 inches (7.62 cm) long x 1/2 inch (1.27 cm) wide x 1/4 inch (.64 cm) thick, with holes drilled in each end to accommodate 8-32 bolts with a spacing between the bolts of 2 inches (5 cm). Use a 5/32 inch (0.4 cm) bit to drill these holes.
- Next, in one of the pieces of Plexiglas, halfway along its length and centered, drill a hole completely through the Plexiglas using a 1/8 inch (0.32 cm) bit and tap an 8-32 thread for accommodating a short rod with an 8-32 bolt. A short rod (Figure 9), with an 8-32 bolt, is screwed into this hole and then the short rod is connected to a table mount using a connector (Figure 8).

- Spray paint the two pieces of Plexiglas, the 8-32 bolts, and the wing nuts with enamel flat black paint and allow to dry thoroughly before assembling the optic mount.
- When screwing in the short rod, make sure it is tightly secured.
- Additionally, the 8-32 bolt on the end of the short rod should not protrude above the surface of the Plexiglas piece in the area under the band aid cushion. This would interfere with the optical component resting snugly against the cushion.

Note: a small band saw with a fine toothed blade is very handy for cutting Plexiglas and aluminum. A hacksaw with 18 teeth per inch will work also.

To cushion the clamping force of the two pieces of Plexiglas tightened by the bolts and wing nuts, I use cut pieces of band aids. The cotton provides the cushion and the adhesive side helps attached them to the Plexiglas. Another great cushion material is the soft portion of Velcro. I've found that the cotton portion of the band aid has a tendency to produce fibers that stick out and can interfere with the beam. Velcro does not have this problem.

For directional mirrors larger than mentioned above, the optic mount in Figure 11a does not work well. You will have occasions to use one or more 4 inch x 5 inch x 1/4 inch thick (10.16 cm x 12.7 cm x 0.6 cm thick) or 5 inch x 7 inch x 1/4 inch thick (12.7 cm x 17.78 cm x 0.6 cm thick) directional mirrors. Figures 11c & 11d show a mounting technique you can use for mirrors of this size using Plexiglas. The mirror shown in both Figures is 4 inches x 5 inches x 1/4 inch thick (10.16 cm x 12.7 cm x 0.6 cm thick). The Plexiglas mount is slightly less in size than the mirror itself although the mount could be the same size or a bit larger than the mirror size. Figure 11e shows the Plexiglas mount cut to size and unpainted.

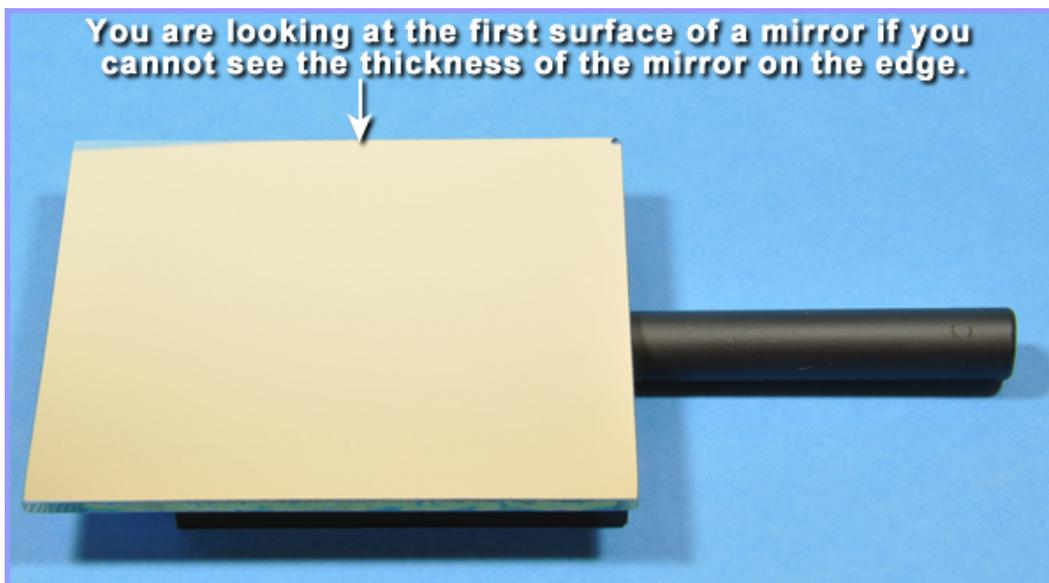


Figure 11c: Large front surface mirror mount showing front surface facing up.

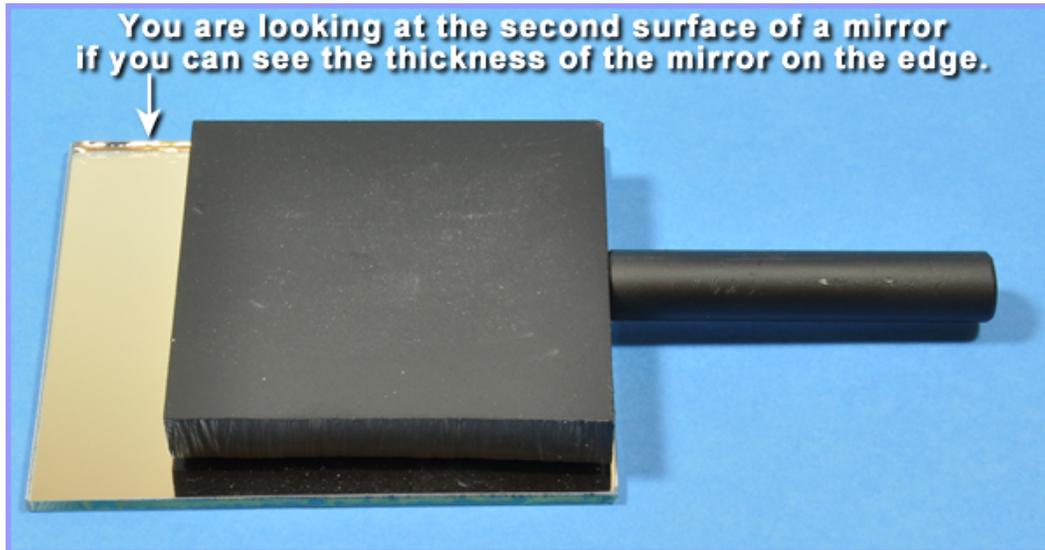


Figure 11d: Large front surface mirror mount showing back side of mirror.

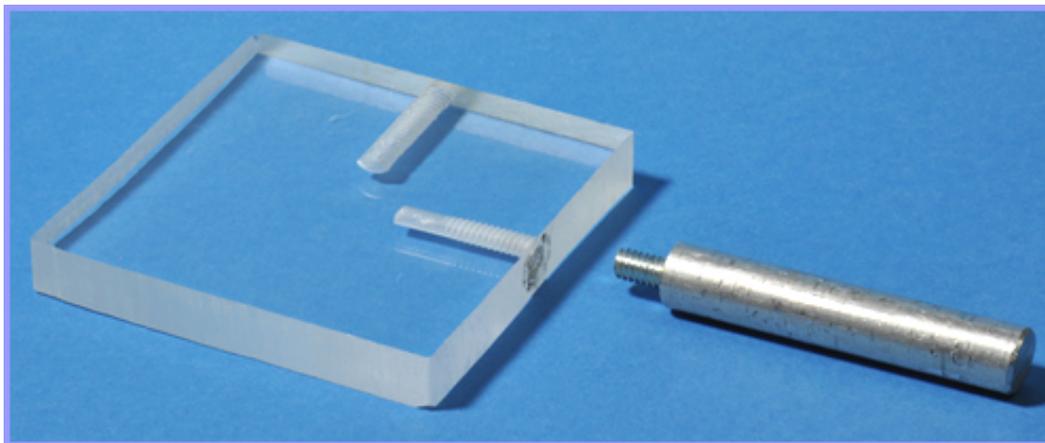


Figure 11e: Large mirror mount cut to size, tapped, and unpainted.

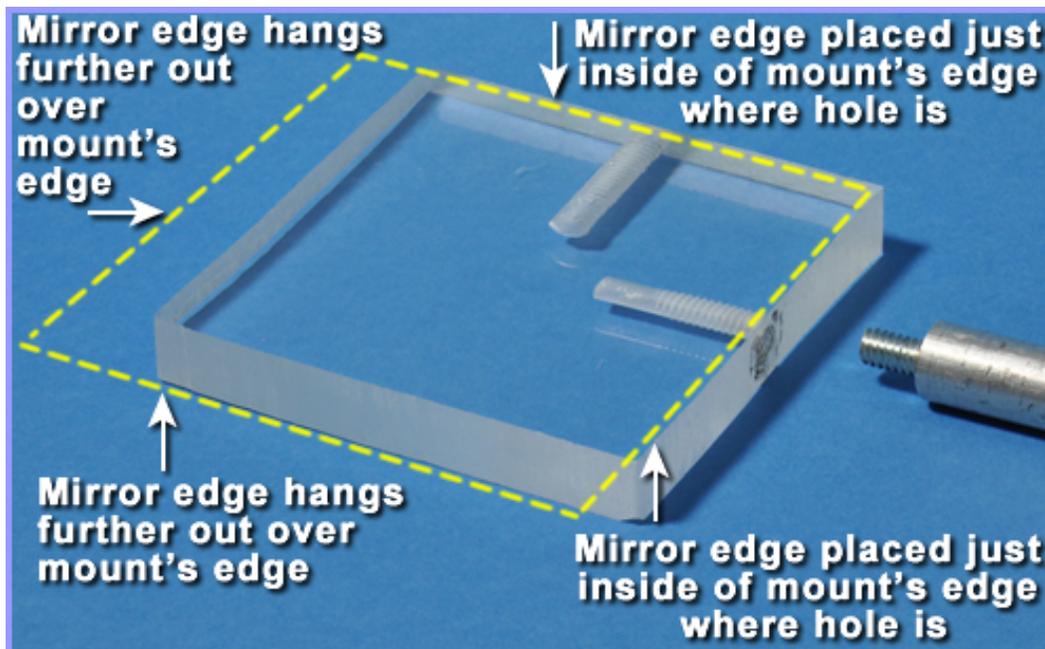


Figure 11f: Important large mirror placement on Plexiglas mount.

Drill and tap a hole half way along and centered on one 4 inch (10.16 cm) side and do the same on one 5 inch (12.7 cm) side to accommodate a short rod with a 1/4-20 bolt as shown in Figure 11e. Use a 3/16 inch (0.48 cm) drill bit and drill the hole 1 inch (2.54 cm) deep. You need this larger bolt size, instead of the 8-32 bolt size, to give better stability for the larger sized mirror and mount. Why two holes for the short rod? If you're setting up your plate holder with the 5 inch side of the holder orientated vertically for recording a vertically orientated figurine, for example, you will want to orientate the 5 inch side of the mirror vertically to get adequate light coverage of the plate. The two tapped holes let you reposition the short rod, and therefore the orientation of the mirror, to accommodate the orientation of your plate holder.

Spray paint the Plexiglas mount with enamel flat black paint and allow to dry thoroughly. Attach the short rod to the mount tightly. Next, epoxy the mirror to the Plexiglas surface making sure the reflective first surface of the mirror is facing away from the mount as shown in Figures 11c & 11d. The mirror, mount, and short rod are then attached to a table mount using a connector.

Note: When you epoxy the mirror to the mount, make sure the edge of the one 4 inch (10.16 cm) side of the mirror is a bit inside the 4 inch (10.16 cm) edge of the mount where the tapped hole is. The same should be done with the 5 inch (12.7 cm) side of the mirror on the 5 inch (12.7 cm) edge of the mount where its tapped hole is. See Figure 11f above. This means that the other two sides of the mirror will be extended further out over the other two sides of the mount, which is fine. The reason for this is that you may not be able to get your holes drilled exactly centered on the 1/2 inch (1.27 cm) thickness of the Plexiglas mount which means that when you screw in the short rod in either hole, the edge end of the short rod might stick out above the mounting surface of the mount and not be flush on both sides of the mount even though the diameter of the rod and the thickness of the mount are the same. If the mirror edge stuck out over these mount edges, you would not be able to screw the short rod tightly against the edge of the mount, which is **critical** for stability.

If down the road you plan to make 8 inch x 10 inch (20.32 cm x 25.4 cm) holograms or larger, the optic mounts for 8 inch x 10 inch x 1/4 inch thick (20.32 cm x 25.4 cm x 0.6 cm thick) mirrors and larger require their own special design. If you contact me, I'll be happy to send the designs for these types of optic mounts.

Laser

The laser needs two table mounts as shown in Figure 12. The table mount poles are connected together with a 1/2 inch (1.27 cm) diameter solid aluminum pole running between them and connected to each table mount pole. The length of the connecting pole will be determined by the width of your laser. The laser sits between the two mounts. At the center of the connecting pole is another connector that has a short rod with a 1/4-20 bolt. This short rod with the bolt screws into a 1/4-20 hole in the bottom of the laser housing. Most small He-Ne lasers are supplied with this 1/4-20 hole. Using this mounting technique allows you to easily adjust the height of the laser on the optical table and allows you to tilt the front of the laser up and down.



Figure 12: Table mounts for the laser.

Spatial Filter

If you plan to use a spatial filter, you will need to mount the base of the spatial filter to a 3 inch x 2 inch x 1/2 inch thick (7.62 cm x 5 cm x 1.27 cm thick) piece of Plexiglas as shown in Figure 13a. Once you've cut your Plexiglas mount, lay the spatial filter's base on top of it. The spatial filter base has three holes drilled in it to accommodate 1/4-20 bolts, but you will just be using the front two holes.

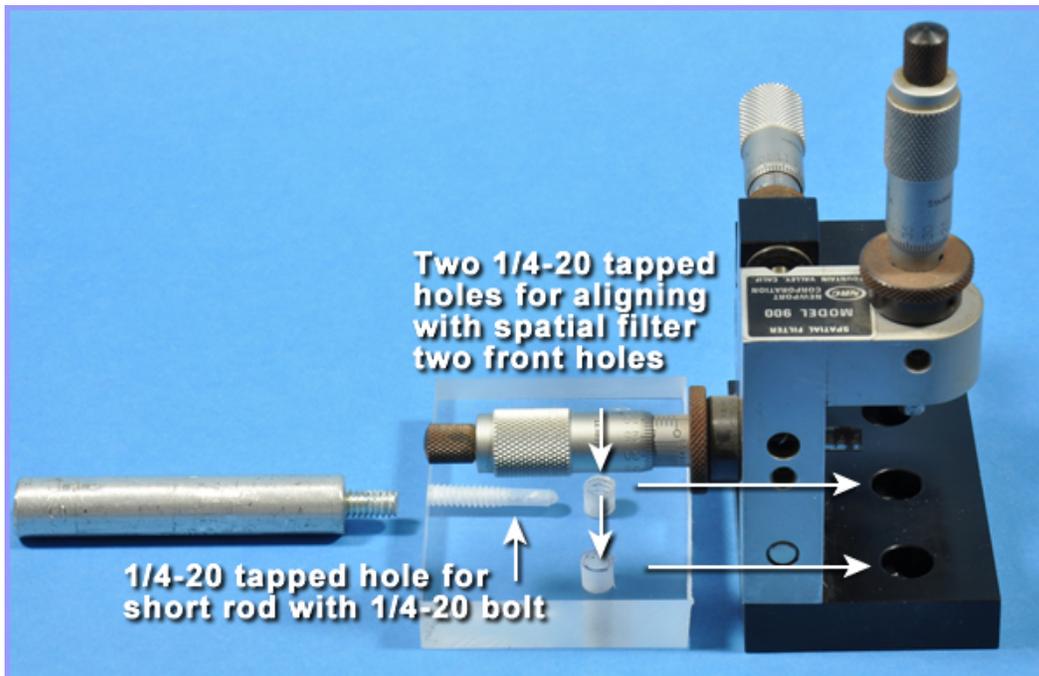


Figure 13a: Mount for the spatial filter.

- Referring to Figure 13a again, hold the spatial filter base firmly down on the Plexiglas mount, stick a pencil, pen, or marker into the two front holes and place marks on the Plexiglas mount for drilling holes and tapping.
- Remove the spatial filter from the mount.

- Using a 3/16 inch (0.48 cm) bit, drill holes perpendicular through the Plexiglas mount where you marked them and then use a 1/4-20 tap to create threads.
- Next, on the 3 inch (7.62 cm) side of the Plexiglas mount furthest away from the Plexiglas drilled holes, use a 3/16 inch (0.48 cm) bit and drill a 1.0 inch (2.54 cm) deep hole half way along that 3 inch (7.62 cm) side and centered.
- Using a 1/4-20 tap, create threads for attaching a short rod with a 1/4-20 bolt.

Before you assemble the Plexiglas mount, spatial filter base, and short rod, paint the Plexiglas mount with enamel flat black paint and allow to dry. Now assemble the parts by bolting the spatial filter base to the Plexiglas mount with 1/4-20 bolts and then screw the short rod into the Plexiglas mount tightly as shown in Figure 13b. The completed unit is then attached to a table mount using a connector.

Note: As mentioned previously when gluing larger mirrors to their Plexiglas mounts, remember not to let the spatial filter base hang over the 3 inch (7.62 cm) side of the Plexiglas mount where the short rod hole is drilled so the short rod can be screwed into the Plexiglas mount tightly.



Figure 13b: Spatial filter assembled with mount and short rod.

Parabolic Mirror

In order to mount the parabolic mirror, you should purchase the telescope mirror mount made for this size mirror as shown in Figure 14. Two holes are drilled, opposite one another, in the mirror mount for 1/4-20 bolts using a 1/4 inch (0.64 cm) bit. A short rod with a 1/4-20 bolt is attached to each of the two holes in the mount with 1/4-20 nuts and lock washers. Two table mounts, each with a connector, are attached to the short rods, one on each side of the mount.

I recommend placing and tightening the parabolic mirror in its mount before you attach the telescope mirror mount to the table mounts. You may need someone to help you attach the telescope mirror mount to the table mounts because of its weight. Be very careful not to accidentally scratch the front surface of the mirror. You do not have to paint the telescope mirror mount flat black, but the short rods and table mount poles should be painted with enamel flat black paint.

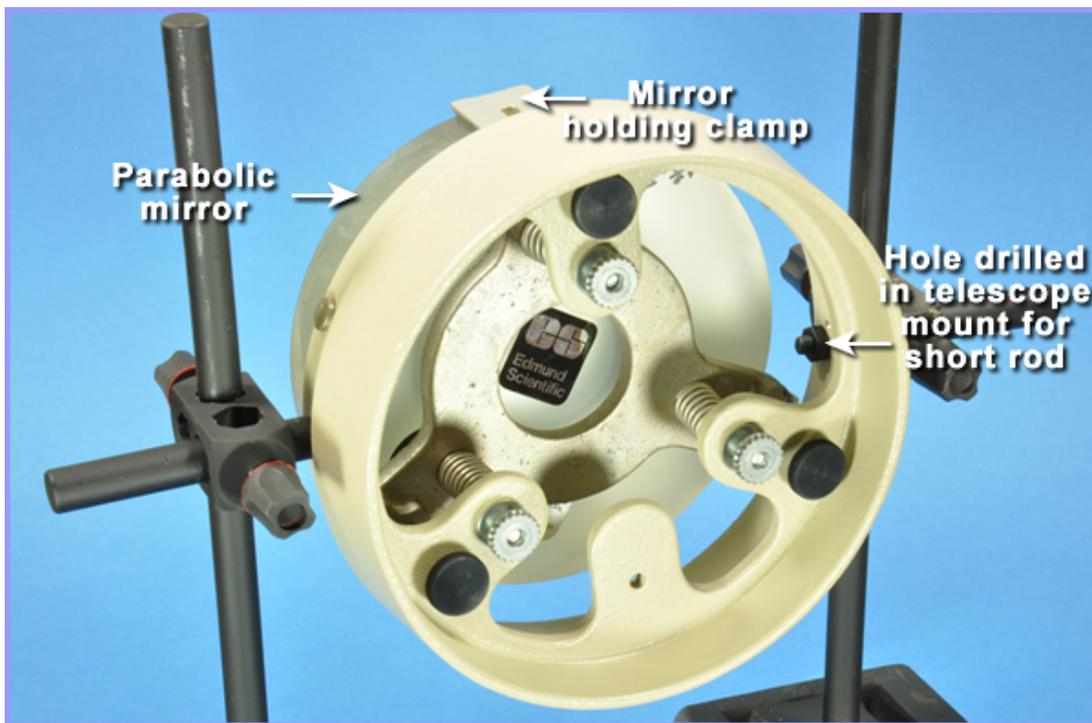


Figure 14: Parabolic mirror telescope mount.

Plate / Film Holder

This system utilizes a 4 inch x 5 inch (10.16 cm x 12.7 cm) hologram plate holder as shown in Figures 12a & 12b. The plate holder is made up of numerous parts as shown in Figures 12c and 12d. These parts include three aluminum bars, two 1/4-20 short rods and two 1/4-20 nuts, two Plexiglas pressure plates, four sets of 3/4 inch (1.9cm) long round head 8-32 bolts, nuts, & compression springs, two Velcro strips, and four 1/2 inch (1.27cm) long round head 8-32 bolts. Figure 12c shows the parts without labeling for clarity.



Figure 12a: Finished plate holder showing front side.



Figure 12b: Finished plate holder showing back side.

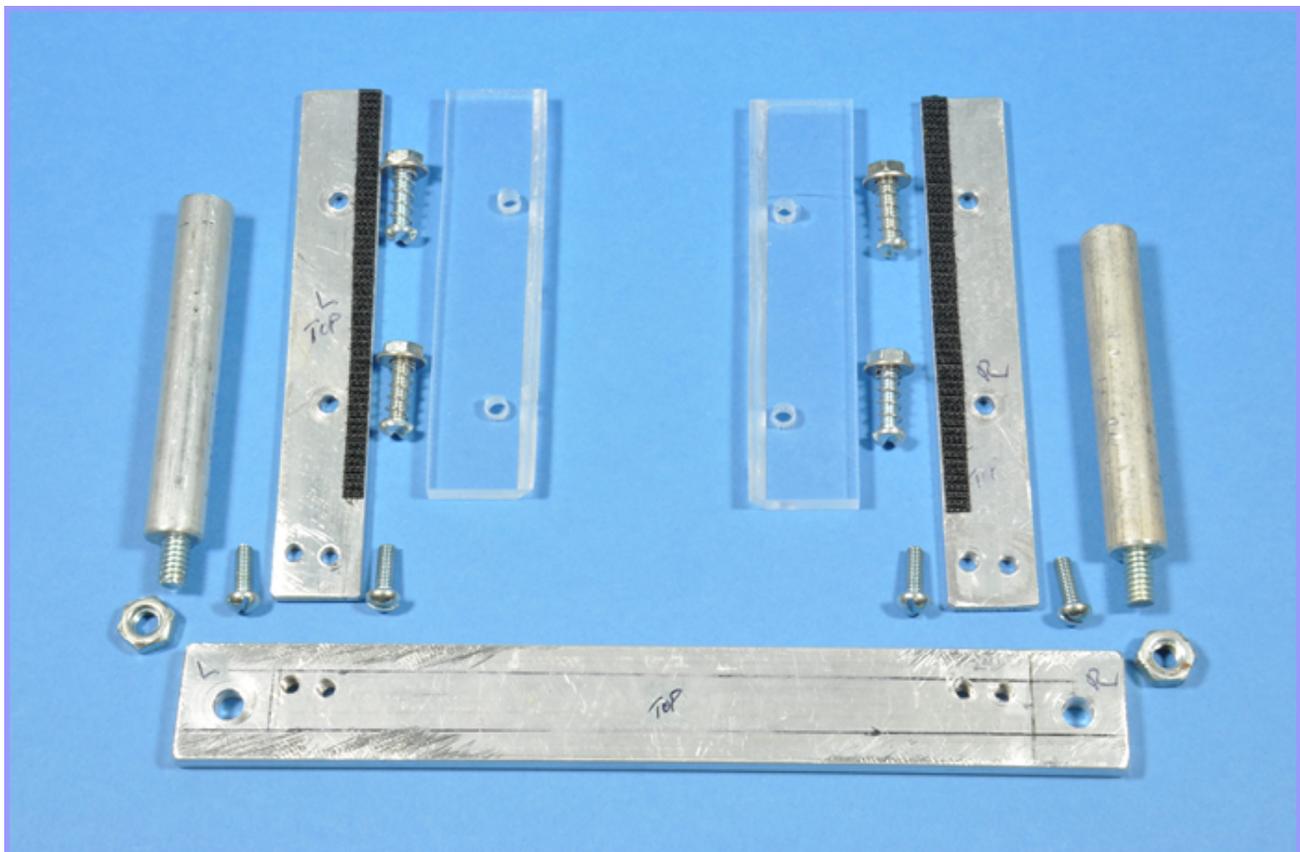


Figure 12c: Plate holder parts and holes without labels for clarity.

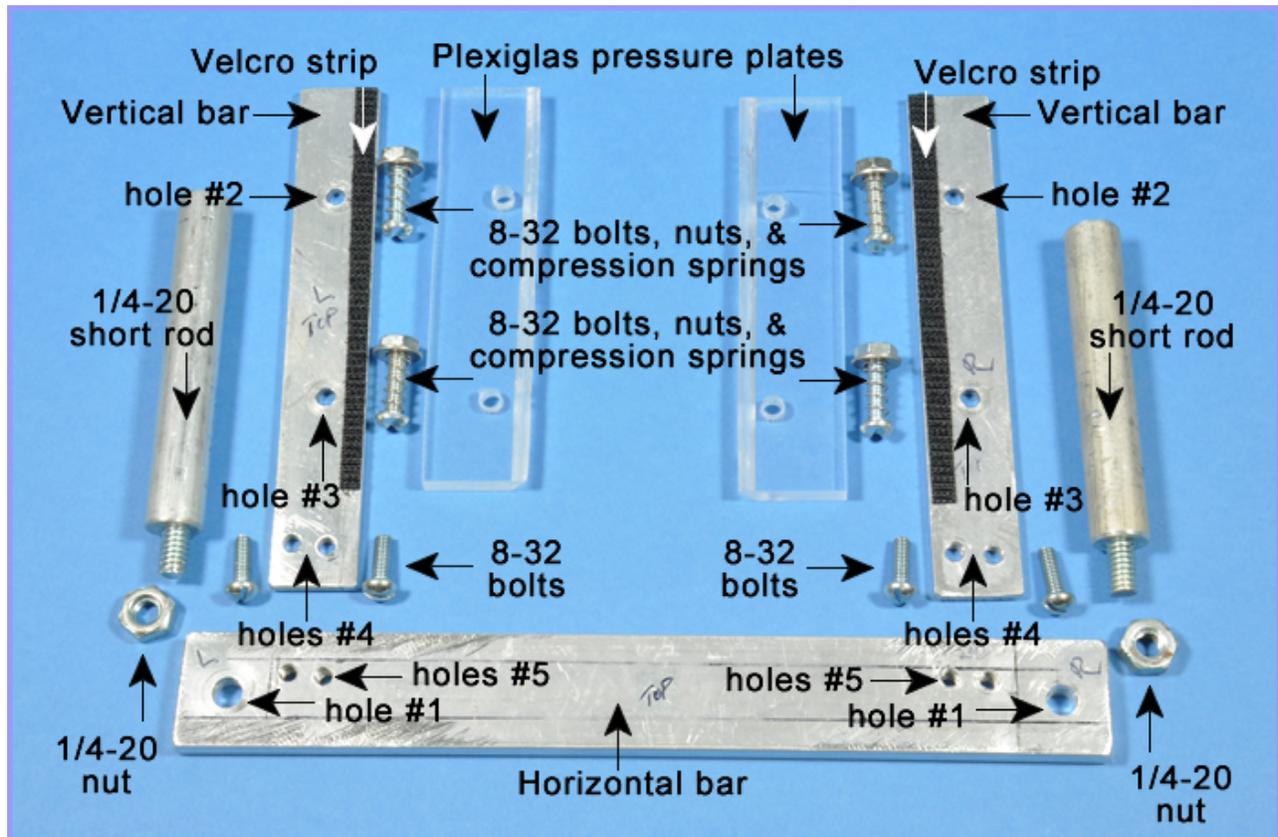


Figure 12d: Plate holder parts and holes with labels.

Three aluminum bars need to be cut for this holder and are available from hardware stores. The horizontal bar is 7-3/4 inches long x 1.0 inch wide x 1/4 inch thick (19.69 cm x 2.54 cm x 0.64 cm). The length of this bar is critical for upcoming measurements, so cut this length as accurately as you can. The two vertical bars are 5 inches long x 3/4 inches wide x 1/8 inch thick (12.7 cm x 1.9 cm x 0.32 cm).

With a pencil or fine/medium point permanent marker, mark one side of the horizontal bar as the "top" (or "F" for front) and do the same with the two vertical bars as shown in Figure 12c. The "top" side of all the bars is the front of the plate holder. You should also mark which vertical bar is the left bar and which one is the right bar and also which side of the horizontal bar is left and which is right when the "top" is facing up. Later on, you will be placing the vertical bars on top of the horizontal bar and you will need to make sure all the "top" sides are facing up and the left/right positions are in the right place. I've suggested a permanent marker so the markings are not accidentally erased. If you make a mistake in placing your markings, you can use lacquer thinner and paper towel to remove them. You'll be painting all these bars with enamel flat black paint so you don't have to remove these markings before you paint.

Before you attach the vertical bars to the horizontal bar, you need to drill some holes in all three bars. Figures 12c and 12d show the locations of these holes and are numbered. Drill a hole (hole #1) on each end of the horizontal bar using a 1/4 inch (0.64 cm) bit to accommodate a short rod with a 1/4-20 bolt and nut for mounting to a table mount with a connector. These holes should be drilled 3/8 inches (0.95 cm) from each end of the horizontal bar and centered 0.5 inches (1.27 cm) on its width as shown in Figure 12e. The plate holder uses two table mounts, one on each side, to provide good stability. Next, you will drill several holes in the vertical bars before you drill the holes in the horizontal bar for attaching the vertical bars.

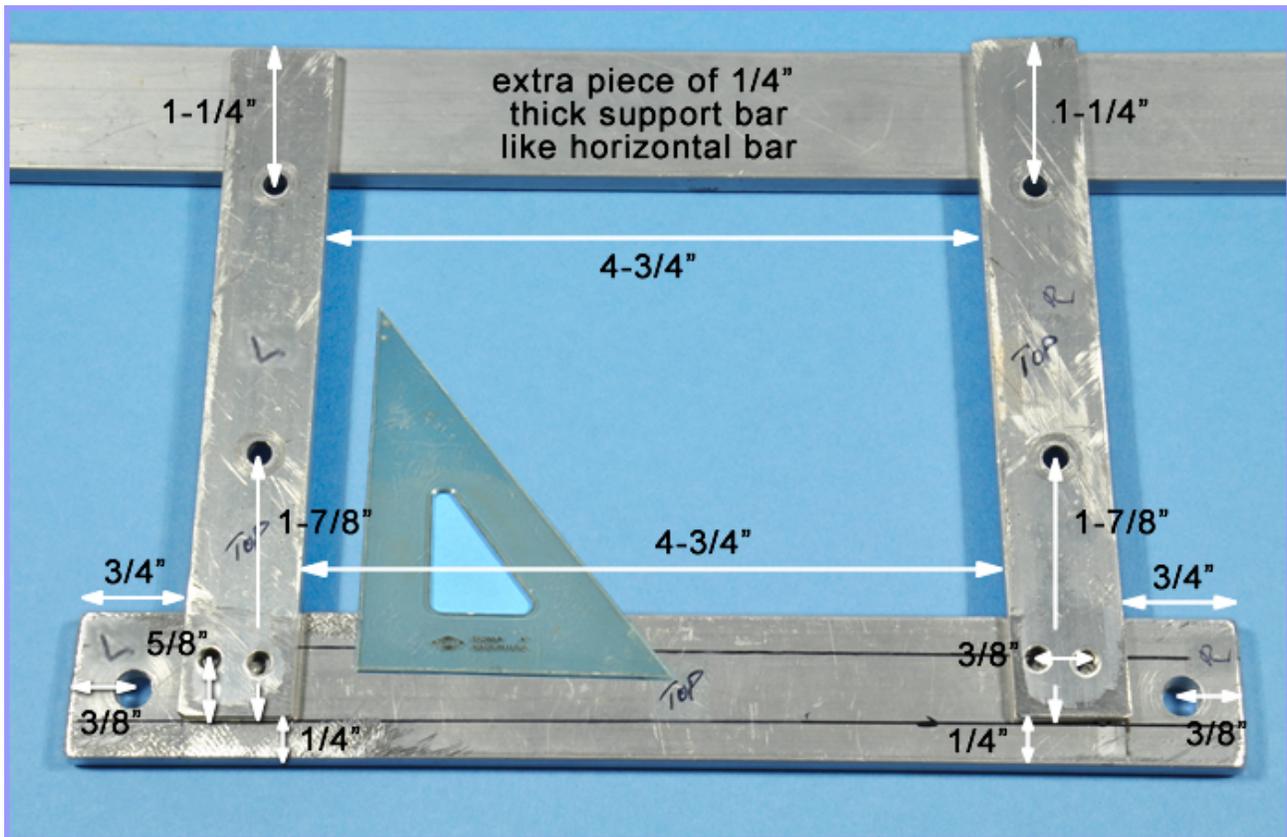


Figure 12e: Positions and measurements of holes.

The photographic plate is held tight to the vertical bars with Plexiglas pressure plates held to the vertical bars with 8-32 bolts and nuts and #9 compression springs. Two holes are drilled in each vertical bar with a $5/32$ inch (0.38 cm) bit for inserting 8-32 bolts and nuts that hold the pressure plates and compression springs. One hole (hole #2) is drilled a distance of $1-1/4$ inch (3.18 cm) from the end of the vertical bar furthest from the horizontal bar (Figure 12d & 12e). This will be the top end. A second hole (hole #3) is drilled a distance of $1-7/8$ inches (4.76 cm) from the end of the vertical bar close to the horizontal bar (Figure 12d & 12e) and the end that will be attached to the horizontal bar. Both holes should be centered in the middle of the width of the vertical bar.

Note: Since the pressure plates apply pressure to the edges of the photographic plate and press the edges of the photographic plate against the vertical bars to hold it secure and stable, these holes are drilled in these positions to provide the best uniform pressure across the photographic plate. This will become important later on when you use photographic film instead of a photographic plate.

Next, using again a $5/32$ inch (0.38 cm) bit, drill two holes (holes #4) in each vertical bar $5/8$ inches (1.56 cm) from the bottom end of each vertical bar (measure from the center of each hole to the bottom edge) as shown in Figure 12e. The center of these holes should be $3/8$ inches (0.95 cm) apart from each other to accommodate the round heads on the 8-32 bolts you will use to screw the vertical bars to the horizontal bar.

Now you are going to place the vertical bars on top of the horizontal bar and use the two holes on the bottom of each vertical bar to mark drill holes on the horizontal bar. This whole process should be as accurate as you can make it when marking the holes to be drilled, their positions, and drilling the holes. So take your time and measure often.

Using Figures 12d & 12e as visual guides, lay the horizontal bar on a table top and then lay both vertical bars with their bottom ends (the ends with the two drilled holes #4) on top of the horizontal bar with "top" facing up for all the bars. Take an extra piece of 1/4 inch (0.64cm) thick bar long enough to place under the top ends of the two vertical bars. This will keep the vertical bars parallel with the table top and make marking the drill holes on the horizontal bar more accurate. Once you get the all the bars in position as shown in Figure 12e, tape down both 1/4 inch (0.64cm) thick bars with duct tape. You don't want these to move while you're positioning the vertical bars.

Let's start with the right vertical bar first, so remove the left vertical bar. Adjust the position of the right vertical bar on top of the horizontal bar so the vertical bar is perpendicularly to the horizontal bar (a small plastic right angle is useful here). Position the right edge of the right vertical bar 3/4 inches (1.9 cm) from the horizontal bar's right end as shown in Figure 12e. The bottom of the vertical bar should be a 1/4 inch (0.64 cm) above the bottom of the horizontal bar as shown in Figure 12e. Double check your measurements and perpendicular alignment. Tape the right vertical bar in place so it doesn't move. Stick a pencil or fine/medium point permanent marker into the two holes (holes #4) in the vertical bar to place marks on the horizontal bar. These marks will be where you will drill holes in the horizontal bar for attaching the vertical bar to the horizontal bar.

Do the same procedure with the left side vertical bar in relation to the horizontal bar's left end. Keep the two 1/4 inch (0.64cm) thick bars and the right side vertical bar in their taped positions while completing the left vertical bar.

Before you drill out these four marks on the horizontal bar and with all the bars taped down, you need to check that the vertical bars are positioned where they should be as shown in Figure 12e. Here's the bottom line: the distance between the inside edges of the vertical bars should be 4-3/4 inches (12.06 cm) from top to bottom. If they are not, then you need to adjust both vertical bars equally on the horizontal bar to obtain this distance between them. If you've already placed permanent marks for each vertical bar, remove them and remark them once you've got the spacing right. This distance is critical so that the photographic plate will seat itself properly behind the pressure plates and against the vertical bars.

Here's the math:

- take a metal ruler and double check the distance of the vertical bars from the ends of the horizontal bar and the distance between the inside edges of the vertical bars.
- the distance from each end of the horizontal bar to the outside edge of each vertical bar should be 3/4 inches and the distance between the inside edges of the vertical bars should be 4-3/4 inches.
- if you add 3/4 inches + 3/4 inches + 4-3/4 inches, they equal 6-1/4 inches.
- then adding the widths of the two vertical bars together (3/4 inches + 3/4 inches = 1-1/2 inches) and adding that length to 6-1/4 inches, gives you 7-3/4 inches, the length of the horizontal bar.

You can now see why it was important to accurately cut the horizontal bar to its correct length since the distance between the vertical bars is based on the distance of the vertical bars from the ends of the horizontal bar. If you need to adjust the vertical bars to achieve the correct distance between them, you do have a bit of space to move the vertical bars more towards the ends of the horizontal bar.

Since the length of a 4 inch by 5 inch (10.16 cm by 12.7 cm) photographic plate is 5 inches (12.7 cm), the distance of 4-3/4 inches (12.06 cm) between the inside edges of the vertical bars allows 1/8 inch (0.32 cm) of each side of the photographic plate to rest against the flat surface of each vertical bar and be held in place by the pressure plates.

Once you've achieved the distance between the two vertical bars and have marked their holes on the horizontal bar, remove all the duct tape and separate the parts. You are now ready to drill out the four holes in the horizontal bar (holes #5). Drill out the holes using a 1/8 inch (0.32 cm) bit. Thread the holes using an 8-32 tap. Now attach the vertical bars to the horizontal bar using 1/2 inch (1.27 cm) long 8-32 bolts. The vertical bars should be attached on the back side of the horizontal bar (the side without the "top" written on it) and the 8-32 bolts inserted from the back side and screwed into the tapped holes on the horizontal bar. See Figure 12b. As a reminder, the "top" side of the bars is the front of the plate holder.

Next, attach the two short 3.0 inch (7.62cm) short rods with 1/4-20 bolts to each side of the horizontal bar with 4-20 nuts and lock washers (Figure 12a, b). These rods should be on the back side of the horizontal bar where the vertical bars are attached.

The final part to make are the pressure plates. Cut two pieces of Plexiglas with the dimensions of 4 inches x 1 inch x 1/4 inch thick (10.16 cm x 2.54 cm x 0.64 cm thick). File the cut edges as smooth as you can. You need to cut or file one 4 inch (10.16 cm) side of each piece to about a 25 degree angle as shown in Figure 12f. A small band saw works well for this delicate cut. The reason for this will be explained shortly. Again, file the edges as smooth as you can. This angular edge of the pressure plate will face the photographic plate and vertical bars as shown in Figure 12g.

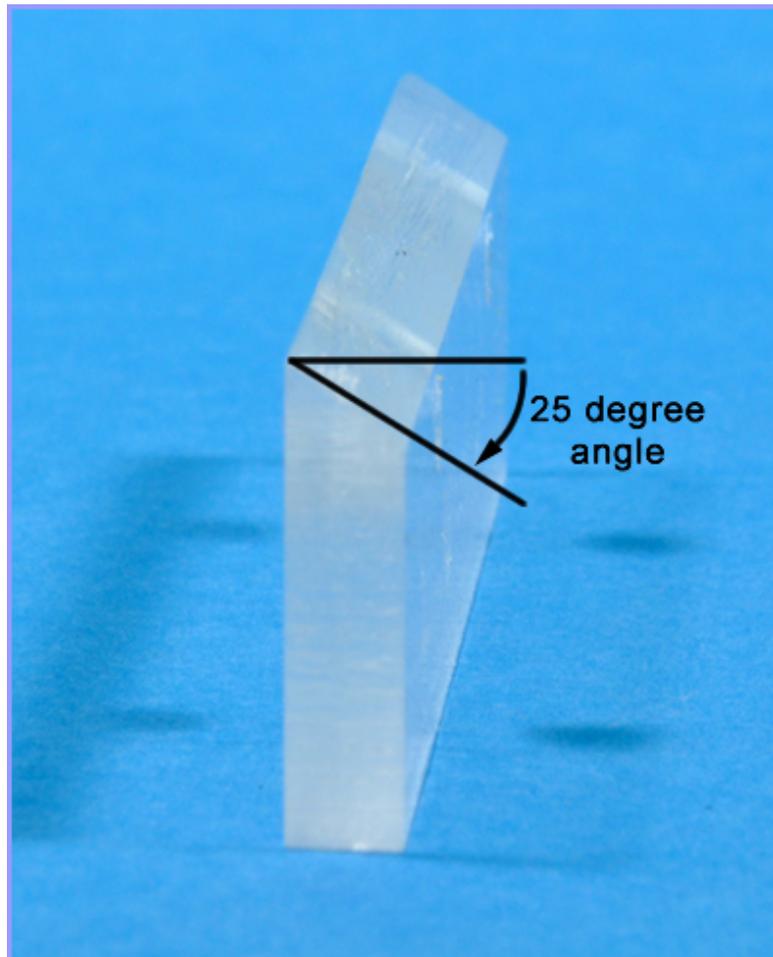


Figure 12f: End view of a pressure plate with 25 degree angle.

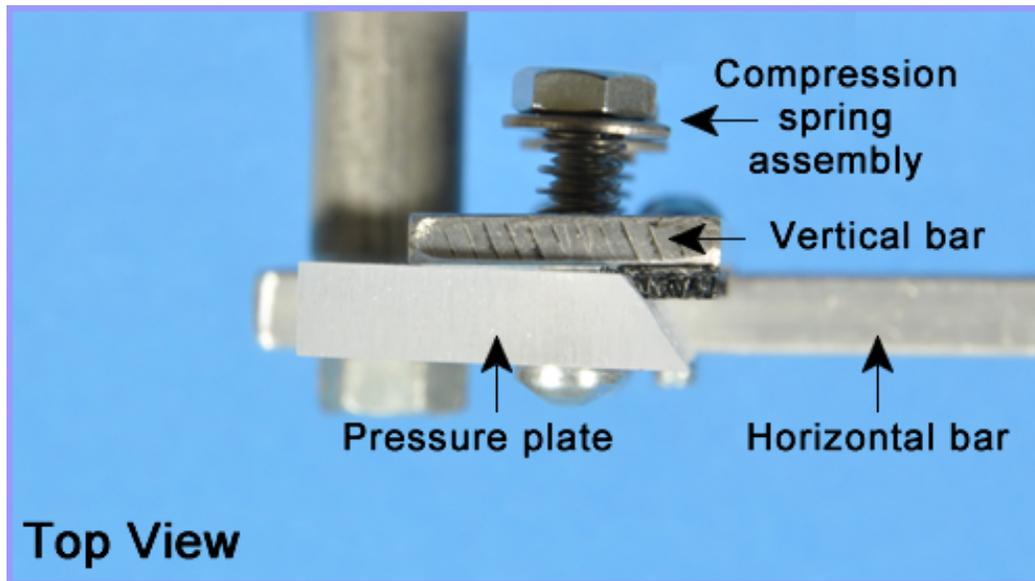


Figure 12g: Close-up top view of pressure plate attached to vertical bar.

Next, you will mark the location for drilling holes in the pressure plates for attaching the plates to the vertical bars. With the plate holder front facing you, take one of the pressure plates and position it in front of the right vertical bar with the angle cut facing towards the inward side of the vertical bar, the angle facing away from the front of the plate holder, and the pressure plate resting on the top of the thickness of the horizontal bar as shown in Figure 12h. Label this pressure plate "R" for right and "F" for front. Now move the pressure plate so its left side is 1/16 inch (0.16 cm) to the right of the inward side of the vertical bar. Once it is in position, hold the pressure plate firmly in place and reach back behind the vertical bar and stick a permanent marker in holes #2 and #3 to mark the drill holes on the pressure plate. Repeat this procedure for the pressure plate on the left vertical bar.

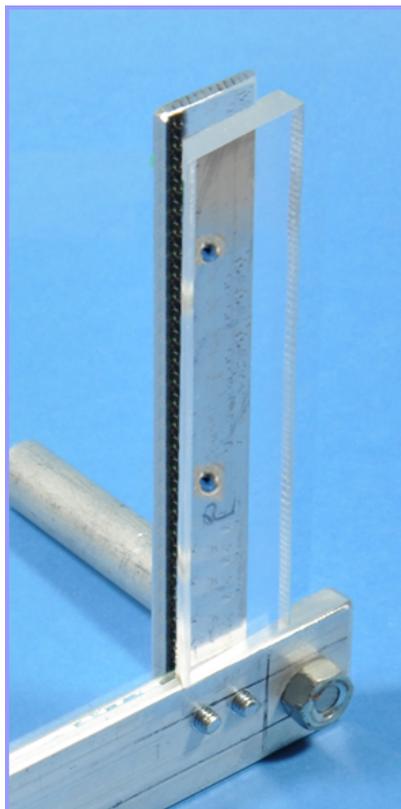


Figure 12h: Pressure plate position for marking drilling holes.

You will now attach each pressure plate to their respective vertical bars using the 8-32 bolt and nut. Insert the 8-32 bolt from the front into the top right pressure plate hole #2 and through the right vertical bar hole #2. On the back side of the vertical bar, place a #8 washer on the bolt, then a #9 compression spring, then another #8 washer, and finally screw on a 8-32 nut to the end of the bolt. Repeat this procedure for hole #3 in both the right pressure plate and right vertical bar. Now repeat both of the above procedures for the left pressure plate and left vertical bar. You may have to cut the length of the compression springs with wire cutters if the original length is too long to get the nut screwed on.



Figure 12i: Showing how much compression in the springs.

Look at Figure 12i to get an idea of how compressed the spring should be after the nut is screwed on and flush with the end of the bolt. There should be a small amount of compressibility left in the spring so you can pull the pressure plate away from the vertical bar a distance of at least 1/16 inch (0.16cm). This facilitates the insertion of the photographic plate into the plate holder. Figures 12j and 12k show the finished, unpainted plate holder with the photographic plate inserted.

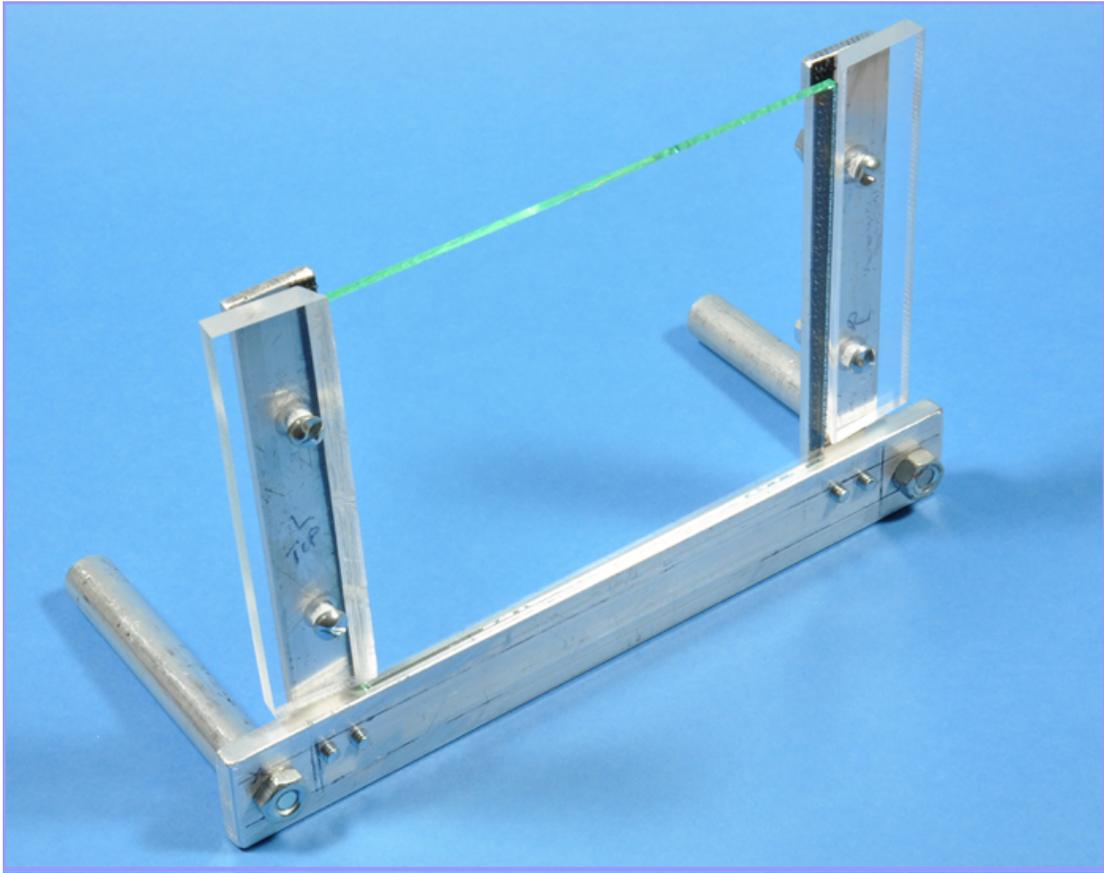


Figure 12j: Front view of unpainted finished plate holder.

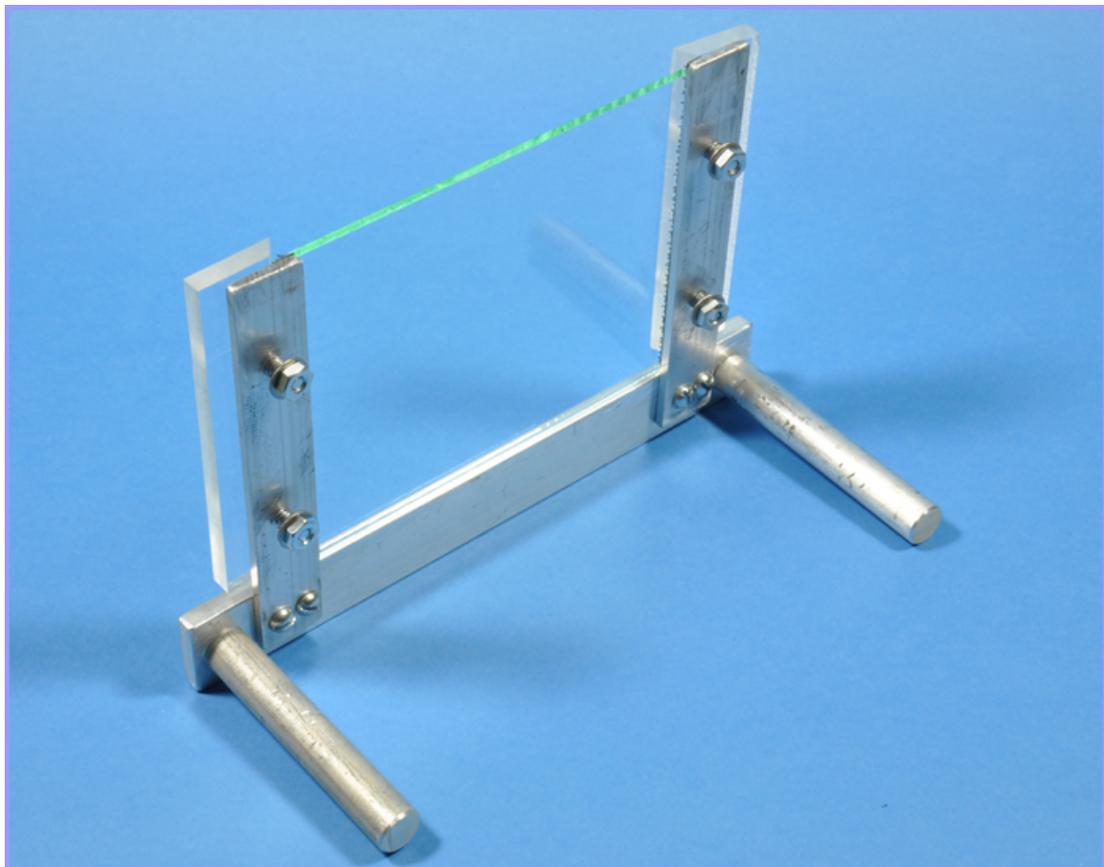


Figure 12k: Back view of unpainted finished plate holder.

The plate holder in Figures 12j and 12k was photographed before I made some modifications to the plate holder described in the above text. So just ignore the fact that in the front view above, the pressure plate is not shown resting on the surface of the horizontal bar. Also in the back view above, a #8 washer is missing between the vertical bar and compression springs.

When you start making your first holograms, I recommend you use photographic plates instead of film to enhance your success in making a good hologram (except when making density test exposures). Later on you can switch to using photographic film which is less expensive than the plates. Film is more difficult to use because it is flexible and must be sandwiched between glass plates, which are then inserted into the plate holder. The ability to pull the pressure plates away from the vertical bars is a great help in inserting these two glass plates since they are twice the thickness of one photographic plate. When I first started making 4 inch x 5 inch (10.16cm x 12.7cm) holograms with plates, some of them didn't come out well, so I saved at least two of these plates to use for sandwiching film. You can remove the emulsion from these photographic plates by soaking them in a solution of 50% bleach and 50% hot (110°-120° F [43°-49° C]) water for about 30 minutes. Most of the emulsion should just slide off but if some of the emulsion is still present, you can use a new single edged razor blade to remove it. You can use a plastic film development tray for the soaking part. Once all the emulsion is gone, you can further clean the plates using a window cleaner.

Once you have the plate holder built, you should disassemble it and paint all the pieces with enamel flat black paint. Once thoroughly dry, you can reassemble the holder. Spray paint the springs just lightly. Otherwise, over time, the paint may chip off from the springs expanding and contracting.

Note: You may have noticed in Figure 12a that the top surface of the vertical bars are white. These are actually small strips of "glow-in-the-dark" phosphorescent plastic from a solar system wall kit. The strips are attached to the top surface with 5 minute epoxy. These strips help you locate the top area of the plate holder for inserting the photographic plate or sandwiched film when room lighting is under certain safe light conditions or non-existent. This strips will glow but not expose the recording emulsion.

3D Object Scene

I will be using "object scene" to mean just one object or a scene of objects. Your object scene should have certain characteristics. It should be three dimensional if you want your holographic image to be three dimensional (having depth-of-field and parallax). You could use a two dimensional object as your subject, like a photograph, but your final image will be a three dimensional image of a two dimensional photograph floating in space. There would be no depth-of-field or parallax in the photograph itself.

Figure 13a shows four, three dimensional geometrical shapes that are painted white, red, blue, and green when illuminated with normal room light.

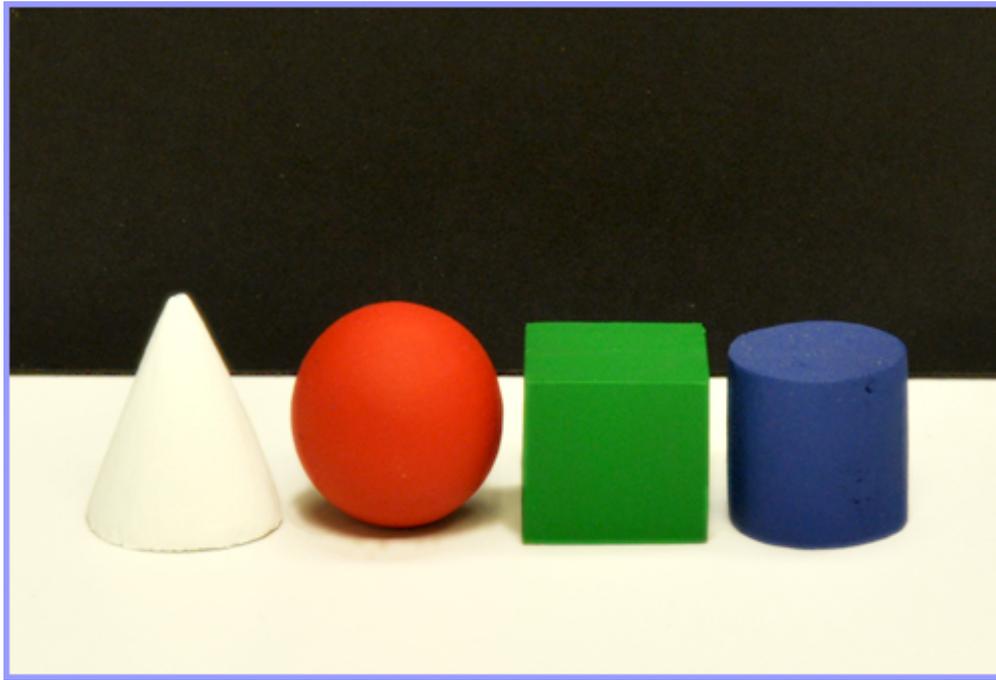


Figure 13a: Illuminated with normal room light.

Be aware that these colors on the objects will be different shades of the laser's beam color in the recorded hologram. Since your laser's beam is monochromatic, so the colors will be monochromatic in the hologram. The objects' colors will not be white, red, blue, and green. Figures 13b & 13c show the objects in Figure 13a illuminated with red laser light and green laser light.

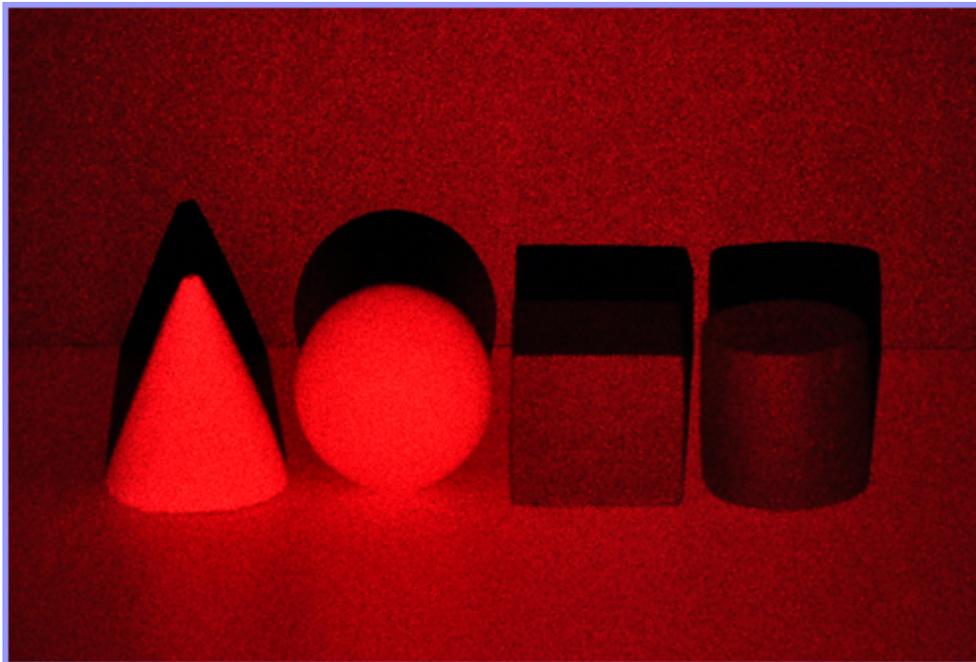
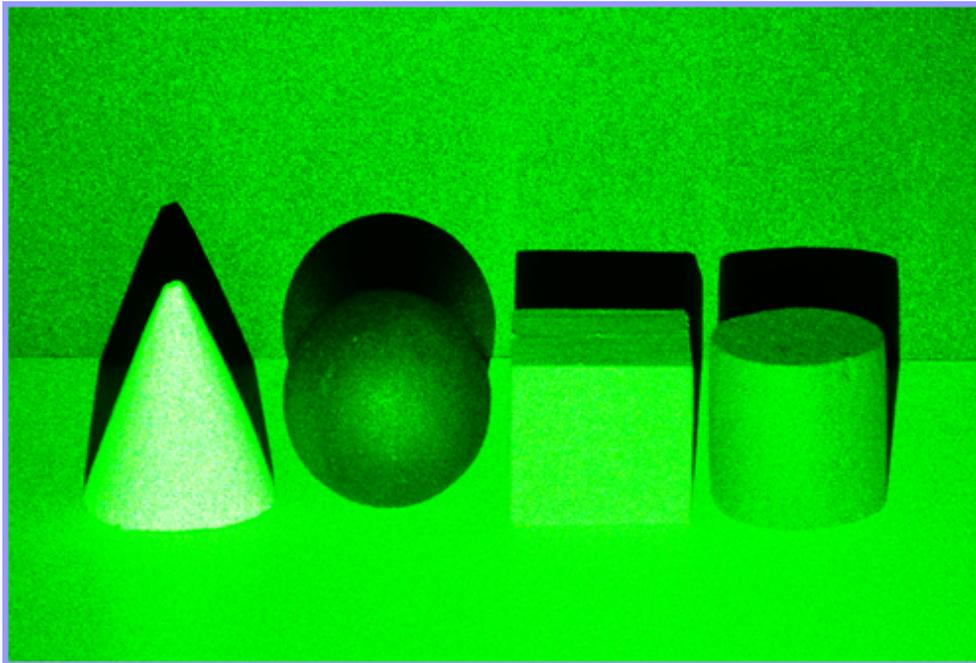


Figure 13b: Illuminated with red laser light.

Under red laser light, the white cone and red sphere reflect more of the red laser light, making them a lighter shaded red. The green square and blue cylinder absorb more of the red laser light, making them a darker shaded red.



13c: Illuminated with green laser light.

Under green laser light, the white cone still reflects more of the green light as does the green square and blue cylinder, making them a lighter shaded green. The red sphere absorbs more of the green laser light, making it a darker shaded green.

The size of your object scene should be smaller than the size of the recording plate you are using if you plan to make a white light reflection display hologram from your transmission hologram. Why? The recorded and processed multi-beam transmission hologram (called H1) will be used to project its real image of your object scene as the "new" object scene to be recorded by the multi-beam white light reflection hologram (called H2). H1 is essentially a window that H2 is looking through. If the object scene of H1 is larger in size than H1's recording plate size, then H2 will not be able to see all of the scene in H1 since H2 will be located a certain distance away from H1. Imagine looking through a window. If you're face is right up to the window, your view is wider, probably 180 degrees. If you're face is 2 feet away from the window, your view is narrower. H2 is usually placed several inches from H1. More on this later in *Creating Transmission Holograms and Reflection Display Holograms*. If you plan to make just a single-beam transmission hologram or a single-beam reflection hologram, your object scene can be as big as you want.

Figure 13d shows a 3-1/4 inch by 3-1/4 inch by 1/2 inch thick (8.26 cm by 8.26 cm by 1.27 cm thick) piece of Plexiglas used as a mount to place the geometrical shapes on. Using a 3/16 inch (0.48 cm) bit, drill a 1.0 inch (2.54 cm) deep hole centered on the length and width of one side of this mount. Use a 1/4-20 tap to create threads. Spray paint the mount with enamel flat black paint. Attach a 3 inch (7.62 cm) short rod with a 1/4-20 bolt to this mount using the tapped hole. You can use any type of platform for your object scene that you want. Just make sure it is rigid, sturdy, or won't move during the exposure. Or you can just place your object scene directly on the table top surface, attaching it securely.

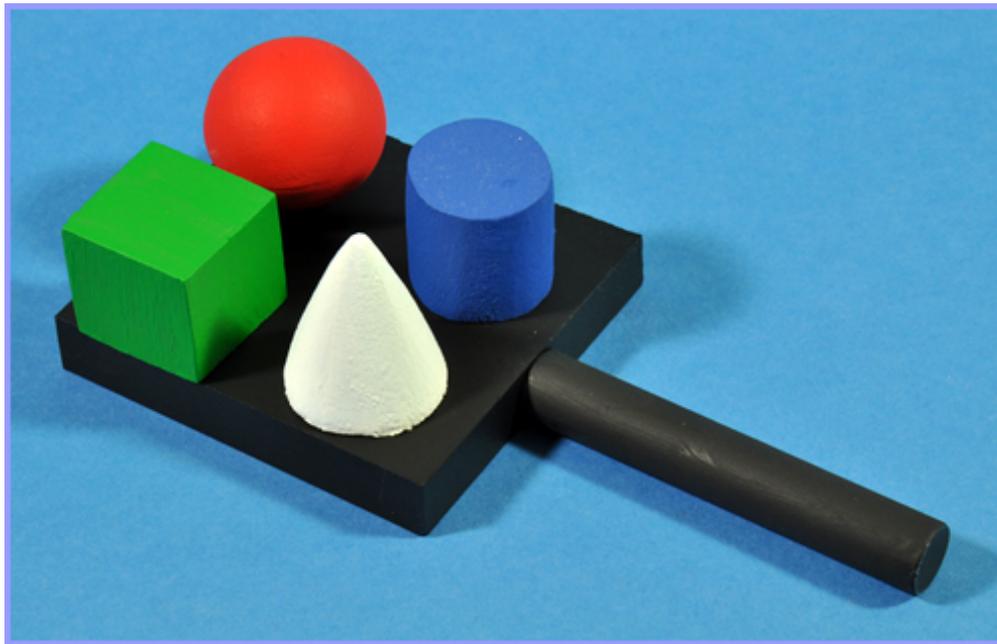


Figure 13d: Mount for three dimensional geometric shapes.

You can attach your objects to any surface with double-sided tape, epoxy, or rare earth magnets. If your objects are heavy enough, you may not have to attach them at all. Whatever way you go about securing your objects to a surface, they must be mounted rigidly enough so they absolutely won't move during the exposure. Another important property of your objects is that they must be rigid themselves. I have never been successful in recording live flowers.

You are now ready to move on to Creating Transmission Holograms and White Light Reflection Display Holograms.