

## Seven Single Beam Projects

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### Abstract

A curriculum for beginning holography classes is presented, consisting of seven different types of holograms, requiring no more equipment than a laser, beamspreader, and a mirror. Of these seven holograms, three are white light viewable, and two of these are image plane types. In addition to the software, hardware in the form of a novel isolation device dubbed the "Big Beam" is described.

### Introduction

As the demand for holograms increases, so does the demand for well-trained holographers. Just as poets must know their ABC's to be in control of their craft, so should holographers know the medium inside-out - so well that the technical aspect is second nature to them. There are certain programs for the elementary teaching of reading and writing, and there should be at least some guidelines for the teaching of holography.

This paper outlines a curriculum, entitled "Seven Single Beam Projects", which illustrates almost all the concepts of wavefront reconstruction through hands-on experience. These projects show the students what is possible with the medium by finding out its shortcomings, limitations, and impossibilities. On the other hand, the students will also see what is so wonderfully possible that no one could ever imagine it without having been initiated into the field at the grass roots level. The students should begin to think holographically, from recording to reconstruction.

### Single Beam Philosophy

No one should pooh-pooh these projects as not being "true holography" for not splitting the beam. They are not just Mickey Mouse science fair projects but have real life applications. Many of the world's more impressive holograms have been made using these techniques, see the examples cited with each project.

Sometimes it is more sensible to go with the simplest set up as less components are used, which cuts down on losses due to reflection or absorption from many surfaces, plus less chance of component movement. Reference and object beams travel essentially the same path, so they are less sensitive to drafts, especially if the area around the equipment is covered. Alignment is less critical, a blessing for pulsed work.

This curriculum has been designed to be catholic in its approach, by training students to make good holograms regardless of whether they are technically or aesthetically oriented. It is best to start out small, so mistakes are less costly, for the learning process includes discovering not only what to do but also what not to do. There is no need to waste student time on more expensive equipment learning the rudiments. All that can be learned earlier in this program. By making the projects single beam simple, troubleshooting becomes easier as less variables are involved.

These seven single beam projects, three of which are white light viewable, and two of those have images which straddle the film plane, require nothing more in the way of equipment than a laser, beamspreader, holographic plate holder, objects, glue gun and a large front surface mirror. This software can be applied to any type of table, steel concrete or sand. But a solution to the problem of cheap, portable yet effective isolation has been found in a novel piece of hardware which I have dubbed "The Big Beam".

### The Big Beam

What simpler shape for single beam work than an optical rail? A tee cross piece at the top prevents the unit from pitching and rocking with its long moment arm. See Figure 1. The beam itself should be 2 to 3 meters long - the major considerations being the desired reference source to hologram distance and/or whether the unit will fit in the holographer's car. There is one practitioner who has a home beam and one for the road for demonstrations. The tee crosspiece should be long enough to straddle two inner tubes.

Wood is the preferred material of construction, not just because it is inexpensive but that it can be easily glued and screwed for semi-permanent attachments. It is rather non-resonant, and certainly very rigid in sizes 4" by 4" in cross-section and larger with the light loading that it will encounter. Good polyurethane varnish and flat black paint are necessary to seal the beam from the effects of humidity. Carriage bolts and wingnuts fasten all the pieces together for easy assembly and disassembly. All the tools the holographer have access to are a saw and a drill with an alignment guide to drill holes into the wood nice and straight.

These units with their three point suspensions and only one axis of symmetry are very hard to couple into a resonant mode. Concrete blocks can be positioned over the inner tubes for added mass. These units have been used successfully in environments as hostile as third floor lofts and fifth floor classrooms. Exact sizes are not given in the blueprint which follows, as this should be an exercise in ingenuity and improvisation with materials on hand, especially for the fabrication of mirror mounts, beamspreaders, object stages and laser holders.

## The Curriculum

Members of this organization may find themselves in a position at one time or another of having to teach a class in holography or having to coach a student's science fair project. This set of exercises is designed to be used as a guide in setting up an educational program, for these suggestions need fleshing out with the instructor's own explanations at a level appropriate for their students. Learning is by doing, and the projects give the students a chance to see what all the equations and diagrams really mean in the lab. Each exercise is designed to grow out of the preceding one, and they can be set up shot, and taken down in one class session. It is recommended that instructors work the bugs out of their systems by preparing their own classroom set of the projects using a common object in all holograms.

It is most logical to start with the first holographic recording set up, that of Gabor<sup>1</sup> (Figure 2), wherein a high contrast black and white transparency is placed in the spread beam inbetween a point source and the holographic plate. Although it is not essential for the student to make this type of hologram, the instructor should have a sample which they have generated to show the attributes of the in-line configuration, namely the simultaneously reconstructed virtual and real images along with the zero-order. But even in spite of these shortcomings, this type of hologram is used for studying aerosol sprays<sup>2</sup> and to record data for high energy physics in the 15 foot bubble chamber at Fermilab.<sup>3</sup>

Project 1b of the historical holograms is the off-axis improvement of Leith and Upatnieks. The object can now be a continuous tone transparency, backlit with a ground glass diffuser. In Figure 3 the bottom half of the spread beam passes through the object, while the rest acts as a reference via a mirror. Again it is not necessary for the student to fabricate one of these but it is important for them to view one to see the improvement in quality by the separation of the zero order and the real and virtual images. The ground glass introduces redundancy into the hologram, and can also be used as a backdrop for transparent objects. This set up illustrates the essence of the holographic stereogram<sup>4</sup>, and how the Library of Congress could possibly be stored in a few filing cabinets.

The second project rearranges the components so that light diffusely reflects off an object to the holographic plate where it meets up with light directly reaching the plate, as in Figure 4<sup>6,7</sup>. These types of holograms may be extremely deep - the object can be much longer than the coherence length of the laser due to its placement within the holodiagram<sup>8</sup>. It is fun to project the real image of the hologram with an undiverged laser beam onto a piece of paper. Some of the most sophisticated holographic artwork has been done with this set up, viz. the work of Doug Tyler<sup>9</sup>.

Project 3 is the workhorse with the most practical applications. Portraiture has been done in this mode, studies of milling machines in situ have been made with this set up<sup>10</sup>, and some commercial holo-cameras use this configuration for NDT. The object is illuminated with laser, and a front surface mirror is placed near to it, to either side or above or below. This mirror directs the rest of the beam to the hologram as a reference beam. Care should be taken to equalize the beam path lengths. See Figure 4<sup>11</sup>. The K ratio can be varied by positioning the reference mirror in various parts of the Gaussian beam profile, or by using a semi-silvered reflector or a black mirror<sup>12</sup>. This set up lends itself to all types of experiments, such as multi-channeling, coherence length tests<sup>13</sup>, and all sorts of interferometric investigations.

The real image from this type of hologram is the "object" for Project 4's hologram, which will be called here as the "Pseudo-Achromat Image Plane Transmission Hologram"<sup>14</sup>. The master hologram is peaked for brightness and signal to noise ratio by exposure and development manipulation. The spread beam illuminates the whole of the first hologram, H1, to project the real image onto a second holoplate, H2. The light missing the H1 goes directly to H2 as a reference beam, Figure 6. Illuminated with laser light, this H2 will reconstruct an image that straddles the film plane<sup>15</sup>, while using white light as the reconstructing source reveals a black and white image near to the plate, which becomes dispersed further away. A shallow object minimizes longitudinal chromatic aberrations, while exact time reverse optics in the transfer step minimize spherical aberration. If large lenses are not available then the longest possible distance from point source to holograms in the mastering and transferring steps will have to do. This project prepares the student for greater understanding and appreciation of the full-blown Benton style achromat and the "rainbow" white light transmission holograms.<sup>16</sup>

Project 5 rounds out the transmission projects with the cylindrical hologram,<sup>17</sup> because if you're going to go 3-D, then why not go 360°? The trick to this type of hologram is in holding the film in a cylindrical shape stably. Nevertheless, holograms over a meter in diameter have been made in this manner.<sup>18, 19</sup>

Project 6 introduces reflection style holography in the Denisuk mode.<sup>20</sup> A highly reflective object is placed behind the holoplate in the spread beam<sup>21</sup> as shown in Figure 8. Reconstruction is accomplished not with a laser but with white light. This makes them the most popular project with the students, as well as providing a wealth of projects for further exploration, such as finding processing techniques for the brightest reconstruction,<sup>22, 23, 24</sup> control of color,<sup>25, 26</sup> and the use of pseudoscopic imagery.<sup>27</sup> This type of hologram can also be used for NDT<sup>28</sup>.

A reflection hologram that reconstructs well under laser light provides the "object" for Project 7, image Plane Reflection Hologram. The spread beam passes through a holographic plate and is returned to it in the form of a real image from a previously recorded reflection hologram, so that the image straddles the second hologram<sup>29</sup>. See Figure 9. Millions of dichromate jewelry pendants have been made in this fashion, as well as larger displays.

The next exercise is a Bonus - Diffraction Gratings with virtually any fringe spacing can be made by placing the plate holder and a mirror at the proper angles in the spread beam, as in Figure 10. Project 9 is the "Holoroid". An undiverged laser beam projects the real image from a transmission hologram onto the top piece of film in an SX-70 type film pack. Putting the pack back into the camera ejects the top exposed piece which will develop into a photograph of the hologram taken without any lenses.

### Conclusions

Hopefully this collection of projects is enough to keep students busy for a semester. These exercises work on any scale, certainly lasers with power  $\geq 5$  mW are preferred, but we have been successful at reflection holography with 800 microwatts of He-Ne power exposing 60 by 60 mm plates for 20 to 40 seconds at Columbia College in Chicago's Loop on these units. But at the other extreme, when we had a chance to do not so serious work with a 25 Joule pulsed Ruby laser at Fermilab, the first thing that we did was to spray paint our hands with silver paint and make large Denisyuks of them! These Seven Single Beam Projects provide a firm foundation which will pay off in the students' future adventures in holography, whatever type of laser or recording material might be available to them.

Photographs of successful Big Beams would be a welcome addition to my collection, please send them to me in care of the Lake Forest College Holography Workshops, Lake Forest, IL 60045.

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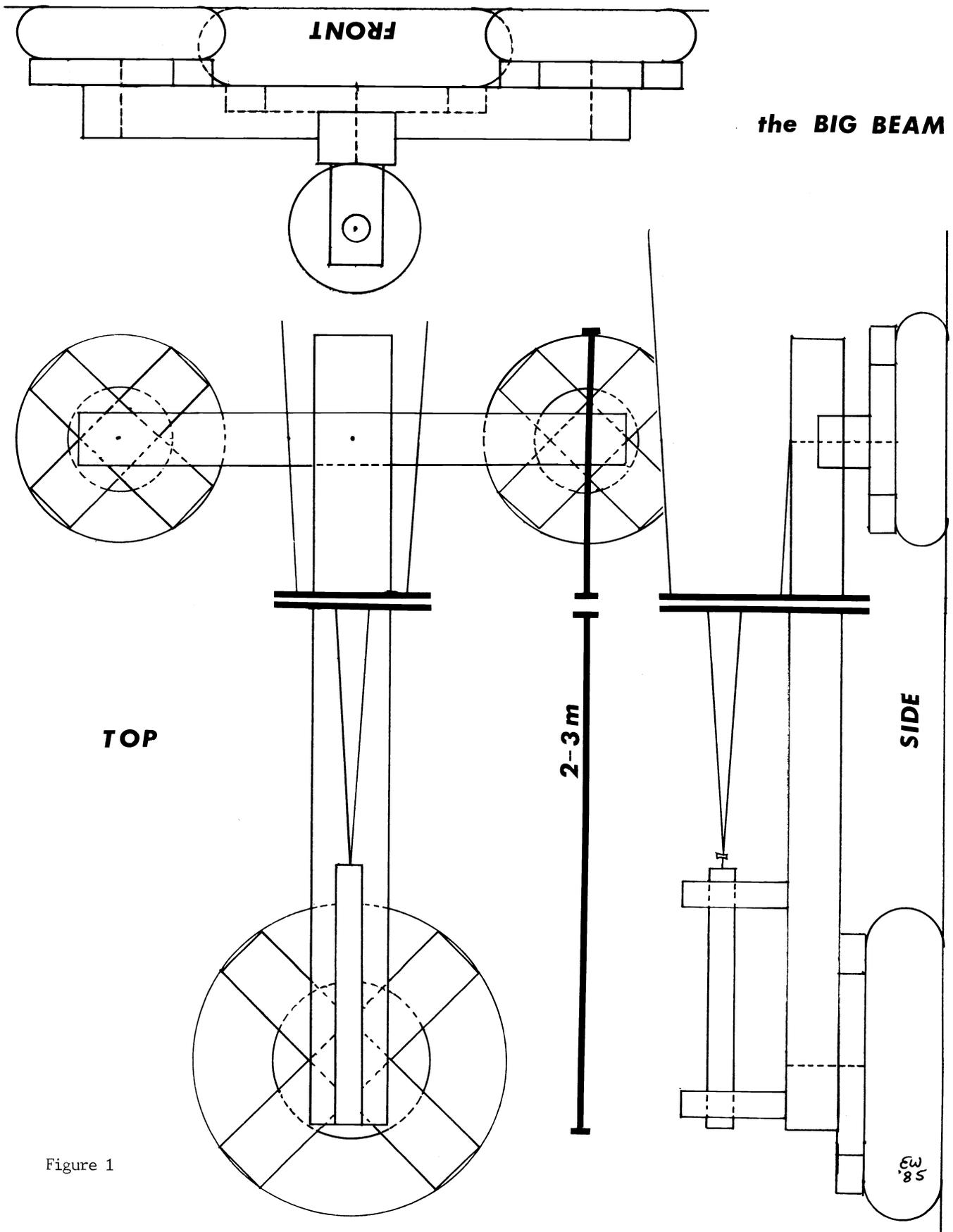


Figure 1

## PROJECT 1a: In-line Holograms

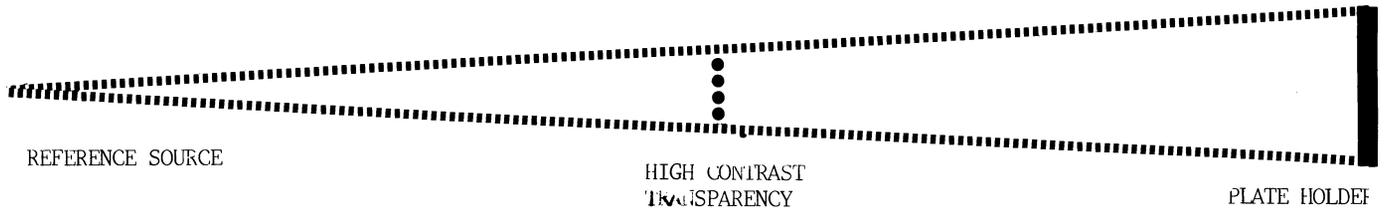


Figure 2

## PROJECT 1b: Off-axis Holograms

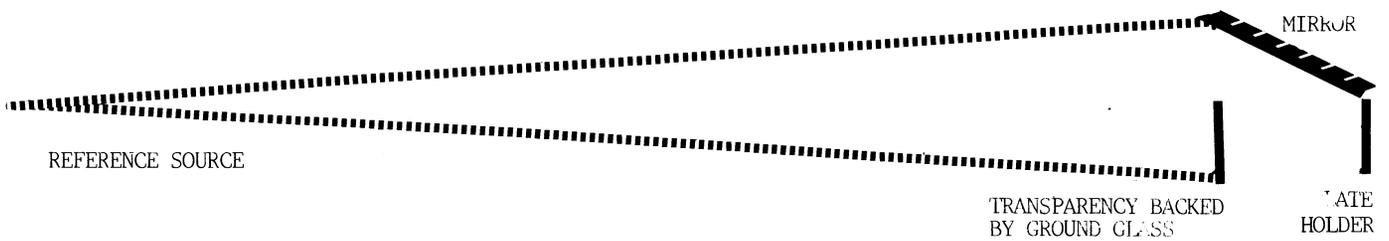


Figure 3

## PROJECT 2: Deep Scene

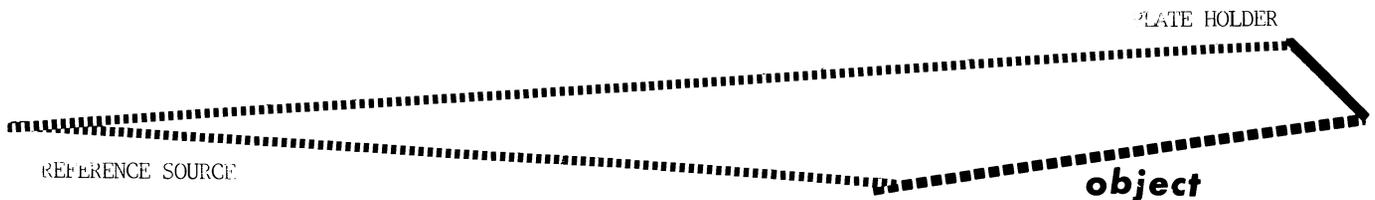


Figure 4

## PROJECT 3: Division of Amplitude

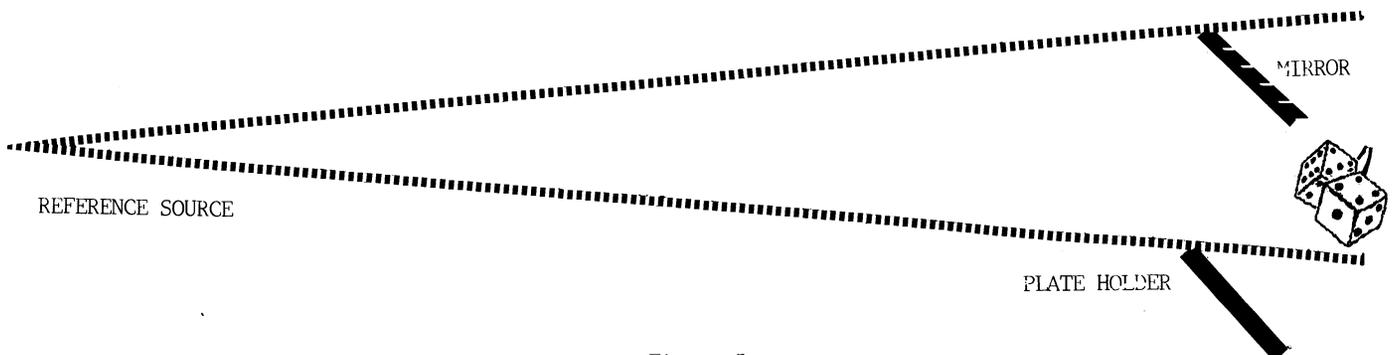


Figure 5

### PROJECT 4: Pseudo-Achromat Transfer

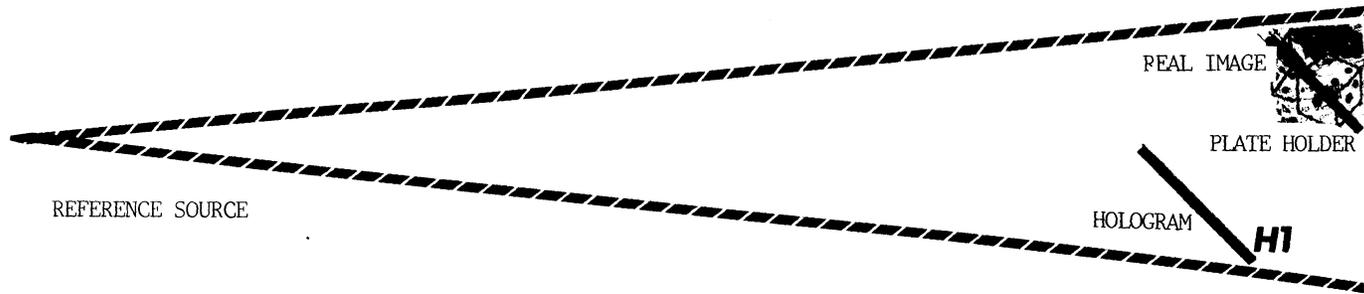


Figure 6

### PROJECT 5: Cylindrical Holograms

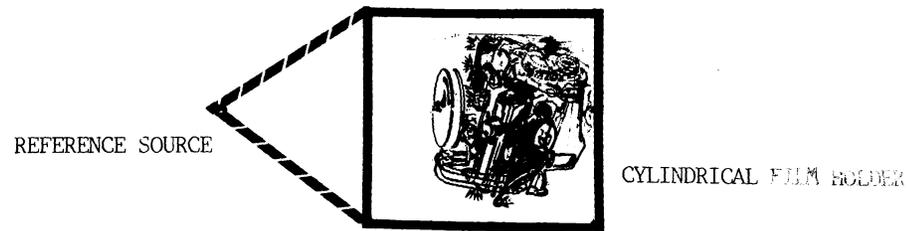


Figure 7

### PROJECT 6: Denisyuk Holograms

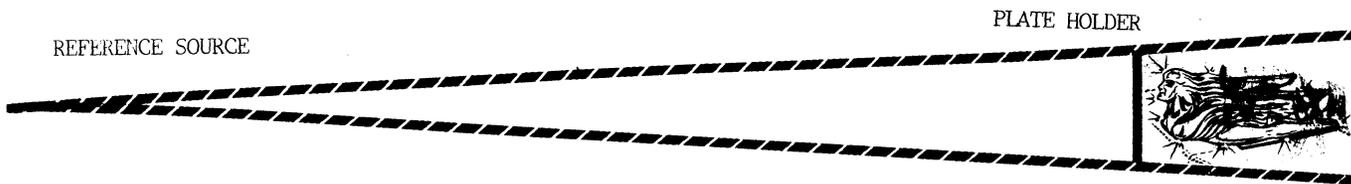


Figure 8

### PROJECT 7: Image-Plane Denisyuk Holograms

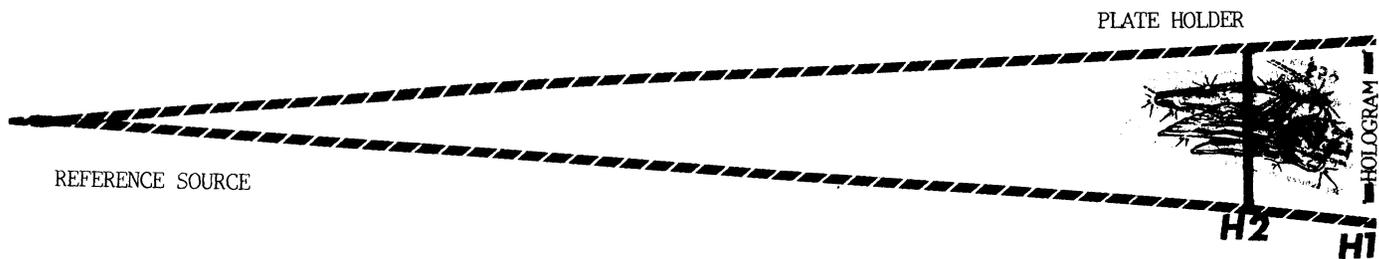


Figure 9

## BONUS! Diffraction Gratings



Figure 10

## BONUS 2!! Holoroids

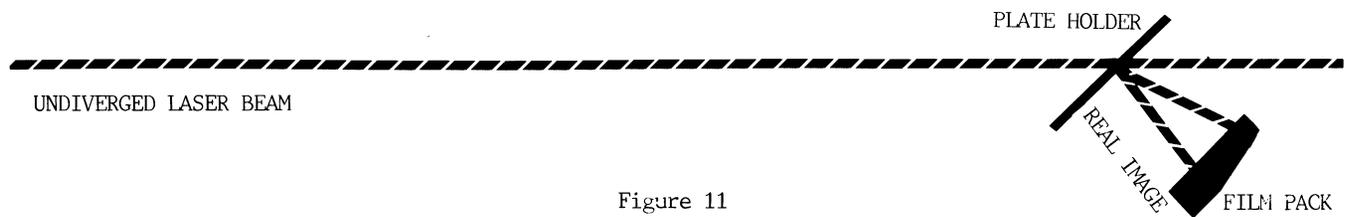


Figure 11