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INSIDE-OUT ENGINEERING:
CHARACTERIZING THE HOLOGRAPHIC STEREOGRAM PRINTER
AT THE SCHOOL OF THE ART INSTITUTE OF CHICAGO

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ABSTRACT

The evolution of The School's Stereogram Printer is traced, with individuals' contributions delineated. The optical performance of the machine is characterized through a series of tests, looking at the system's aberrations and resolution.
Keywords: holography, The School of the Art Institute of Chicago, stereogram printer.

1. HISTORICAL DEVELOPMENT

1.1 Construction of Devices

The optical layout of this device was assembled by graduate student Dean Randazzo while Eduardo Kac took notes. Over the Summer of 1989, on a budget of less than $100 for a flea market 16 mm projector and an electric typewriter chassis to move the slit (the laser and hardware were already in the lab), they made a system rivalling those at commercial holographic labs in quality to produce their own imagery taken from life or computer generated.

The prototype electronic controller was built by the SAIC's very capable electronic technician, Ed Bennett, from bits and pieces of recyclable material that had accumulated at the School over the years. It resembled the guts of a pinball machine, having plenty of 'clunk and thunk' with its washing machine-like circuitry; but, just like the washers at the laundromat, this thing worked day-in/day-out for over a year without malfunction. An improved, slicker controller with thumbwheel controllers for the TTL logic and LED readouts was built by another graduate student, Matt Deschner (MFA 1993), under Mr. Bennett's tutelage.

Matt was requested to name his devices. Instead of Super-Duper Holo-Computer Mark III he chose simply to call the programmable controller "Herman" and its partner, the Stepper Motor Driver, "Evet."

The original format size was an 8 by 10 inch master with slits for 48 motion picture frames to be transferred to an 8 by 10 inch copy film. Expansion has been made to 30 by 40 centimeter-sized masters and copy, with 87 slits, .19" wide. (About 5 mm. Normally we talk metric, but our controller is calibrated in hundredths of an inch.)
Rainbow and achromatic white light transmission copies and reflection copies have been made from the stereogram masters.

In the Holography Studio's first Home the equipment for making the transfers was spread out over two unconnected Newport tables that were not floating. The laser, beamsplitter and spatial filters were on one table; the master and copy plate holders were on the other one.

That set-up was used because of the lack of collimating optics in the lab and the need to 'flatten out' the wavefronts with long throws. Microscope objectives of 5X power with 50-micron pinholes are used to provide a slowly expanding beam that is thrifty with the light. The success rate of this set-up is nearly 100%, barring film movement problems.

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* Now with BEA electro-optics, inc., 640 Pearson Street, Des Plaines, IL 60016.

It was a testimonial to the rigidity of the Newport Tables, the solidity of the basement concrete floors and the persistence of artists with a vision that such a seemingly impossible task could be carried out. But the holographic Camelot did not last for very long.

1.2 Treachery in Academia

In 1993 the School bought a building at 112 South Michigan Avenue, across from the Museum, and it was decided to move the Art and Technology Department to the new site. The Holography Studio was slated to be moved, although it had been working quite well in the 280 South Columbus building. This lab was on concrete floor in a room padded with heavy-duty acoustical insulation. Its previous use had been as an anechoic Sensorium*. For some reason the ceilings were 30 feet tall. It was a perfect home for a holo studio.

However the anteroom was full of junk, literally. Twenty years of industrial cast-offs were stored on shelves reaching to the stars with possible kinetic art projects. But since it was not yet art, there was an awful lot of dirt. An ideal site for inspiration for high tech artists. But a TV tube just slipped off the top shelf one day of its accord, and almost beaned some students, so if we could divorce ourselves from this and start over in a brand new space it would be for the better.

The author and the head of the Art and Tech Department, John Manning, made a plea not to move, as if it works, why fix it, but to no avail. So it was I was commissioned to design a lab to our specifications, in a nice, new, recently rehabbed space.

But unknownst to us there was someone who had an ear (or some say more than an ear) in the Dean's office and persuaded them to cancel the move of holography. I thanked the department head for cancelling the move, but he said he had nothing to do with the maintaining the status quo. Although having to break-in a brand-new space would have been a rewarding challenge, it was a welcome relief, as it was easier not to move.

So the holography studio stayed in its original home** while the rest of the Art and Technology Department sweated over moving, along with the Film Department. Only the Sculpture Department and a Performance Space remained as neighbors in the basement.

But the following school year, the Fall of 1994, on the day before classes started I got hit with the news that Holography was scheduled to move at the end of the Fall semester. Pleading had no effect, as the Sculpture Department*** wanted all the space in the basement.

Like a good soldier, I went along with it. The only space left was a room that had been planned to be Trunk Storage, instead of a well-planned lab. Squeeze into that, otherwise there wouldn't be any Holography Lab. Nor job for me!

The party who should have kept their mouths shut about the move the first time tried to stop this one, but to no avail. They did not volunteer to help at all with the move, which took place in the coldest winter of the decade. (-45°F!)

1.3 A Lemonade Phoenix

There is that tired old saying, if you're handed a lemon, make lemonade. And when you take something apart, you have the opportunity to rebuild it the way you would have liked to the first time. Jesus Lopez worked around the clock to replace the weak links in the system, like wooden supports for mirror mounts with metal pieces.

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* Or was it Sens-O-Rama Room?

** Actually its second home in that building, having been moved prior to 1985 by Ed Dietrich.

*** Nice neighbors. I refuse to comment on what they did with the space, except the slogan, "Holography LIves! (painted by Matt Schreiber, MFA 1995) still survives there.

A variety of improvements have been implemented to the system, mainly through the efforts of Jesus Lopez. These include the installation of a more modern projection optic on the old film projector, with its own **Motor Mike-equipped Translating Stage for Remote Focussing**, the expansion of the reference beam path by a half a table length, with attendant cleaning up of the mirrors and added stability, plus convenience features like reversing slit directions, opening of the shutter electrically during alignment, and remote controls for the **Beam Balance Ratio** and the afore-mentioned **Projection Objective Focussing**. There are no magnetic bases on this table, as all components are screwed into the tabletop, for added stability and tamper resistance.

One of the **Printer's** outstanding features is its versatility to produce other types of holograms, thanks to an extremely stable **Overhead Reference Beam Path** that is designed to cover a 30 by 40 centimeter film at 45 degrees incidence on its short side. With **Beam Stealers** and **Accessory Packages** the **Object Beam Path** can be converted to produce **ONE STEP RAINBOW SHADOWGRAMS** and **LASER TRANSMISSION MASTERS OF DIFFUSELY REFLECTING OBJECTS** or of **TRANSMISSIVE OBJECTS** in conjunction with the locked into position **Reference Beam Path**. This same **Reference Beam Angle** is the one used on the **Transfer Table**, also.

The length of the **Reference Beam Path** is made as long as possible to flatten out the wavefront to approximate a collimated beam, useful for lowering aberrations in the **Real Image To Be Transferred**. The expanding beam traverses the **Printer Table** 2 1/2 times, the half table length being picked up from starting the **Reference Beam** expanding from its **Spatial Filter** immediately after the **Beamsplitter**. This pathlength is over 8 meters long, >10X the length of the diagonal of the **Film Format**.

2. A TOUR OF THE HOLOGRAPHIC STUDIO*

2.1 The Tables

The foundations for the SAIC **HOLOGRAPHIC STEREOGRAM PRINTER** and **TRANSFER TABLE** are a **Newport Research Series Table Top Model No. RS-410-12**. It is supported on four **Newport Model XL-A Pneumatic Vibration Isolating Legs**, which are filled with pressurized air from a **Sanborn 3 1/2 Horsepower Air Compressor**. Three of the **Legs** have **Regulators** on them, so they are **Slaves** to the **Master**, which is the one without. The **Regulators** have **Level-Sensing Valves** on them, and will prevent the table from resting on the **Restraint Stops** at the upper and lower positions. The pressure on the legs is approximately 50 psi. These legs are so effective that **Stereogram Frames** have been exposed while the **Compressor** is running, filling its tank, and have been no different than those made with the noise off!

Surrounding the table, Velcro'ed to their **Support Structure**, are the **Acoustical Vibration Isolating Panels**. They are composed of a Sintra-Styrofoam-Sintra sandwich, with a inch by inch and a half patch of the **Fuzzy Part of the Velcro** screwed to their corners.

2.2 Laser

The source of photons for the Printer set up is the SAIC Holography Department's trusty **Spectra-Physics Model 127-35 helium Neon Laser**. The **Laser** is a light source also generating large quantities of heat. It is mounted up off the **Table** so that air can flow all around it with a pair of **ThorLabs 6" Stainless Steel Posts** capped with **Custom-made Aluminum Baseplates**, at roughly the height of the **Center of the Holographic Plateholder**. Since the laser has slots which emit large amounts of collateral radiation, venting is provided to eliminate the heat, while shielding the set up from the garbage light.

2.3 Beamsplitter

Beamsplitting chores are handled by a **Newport Model No. 930-63 Variable Attenuator/Beamsplitter**, which has been modified by having the second **Half-Wave Plate** removed, its **Polarizing Beamsplitting Cube** rotated for mounting

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* Some of this section may sound pedantic, as it is excerpted from Ed Wesly, *Instruction Manual for Holography Studio*, M^3 Visual Research Laboratory, Chicago, 1995. But it was deemed as worthwhile for some neophytes and old pros who need a chuckle.

simplicity, and the **Rotating Half-Wave Plate's** mounting rotated so that the adjustment knob is on the bottom and the **Beam Balance Ratio** can be changed without fingers getting in the way of the laser beams. Now the fingerknob has a little rubber wheel which is in contact with a small, heavily gear-reduced DC motor so that the holographer can remotely tune the ratio. (Courtesy of Sr. Lopez.) The Model 930 is screwed onto a **Newport Model 340-C Clamp** which holds the **Beamsplitter** at the right height above the table on a **Newport Model 45 Damped Rod** screwed into the **Tabletop.**

2.4 Reference Beam Path
After the Reference Beam exits the Beamsplitter vertically, it is headed on its horizontal path by a **Newport Model 670-TC,** mounted atop a **Newport Model 45 Damped Rod** above the **Beamsplitter.**

2.4.1 Half-Wave Plate
A **Melles Griot 02 WRM 023 Mica Half-Wave Retardation Plate** sits in a **M[31] Visual Research Laboratories Rotating Mount,** bolted to the **Table** via a **Newport Model PH-6 Post Holder** and **Steel Rod** and **Right Angle Clamp,** so that it can be tilted so that the **Laser Beam** is incident along the **Wave-Plate's normal.** This unit is used to vertically orient the **Reference Beam's Polarization Vector** for minimum woodgrain. Rotate the **Half-Wave Plate** while observing the reflection off the cover glass of the **Holographic Platehoder.** When the reflection is minimized, the woodgrain is, too! There is a locking knob on top of the device, release it before rotating the **Wave Plate.**

2.4.2 Spatial Filter
Beam cleaning is accomplished by a **Newport Model 900 Spatial Filter,** equipped with a **5X Objective and 50 micron Pinhole.** This choice of beamspread was predicated on keeping exposure times down, so that there is about one stop of drop of intensity (a halving) from the center to the edge of the **Reference Beam** at the **Holographic Plateholder.**

2.4.3 Iris Diaphragm
This simple device found in the used bins at **Darkroom Aids*** limits garbage light from polluting the **Reference Beam.** Its aperture is centered on a properly aligned **Spatial Filter,** and should not be tampered with, because its usefulness as a guide would be compromised. It can be used to quickly check the tune of the **Spatial Filter.**

2.4.4 Spread Reference Beam Mirrors
There are three of them, starting after the **Spatial Filter** with a **Newport Model 625A-6C** on the **Mirror Stack****. The latter is a **ThorLabs 14" plus 6" Stainless Steel Posts** screwed directly into the table, accomodating a mirror for the **OBJECT BEAM PATH** as well as the formerly-mentioned **6" Diameter Reference Mirror Mount.**

The decision was made to enlarge the **REFERENCE BEAM** before bouncing off this mirror at the edge of the table to to flatten out the wavefront a bit more, so a large mirror was necessary at this post. The **6" Mirror** sends the spreading beam slightly upwards to the opposite end of the table to a **Daedal Model X5700 Mirror Mount** on top of three **ThorLabs 14" stainless Steel Posts** screwed into the **Table** as far back as possible. The mounting screws of the **Mirror Mount** have been reversed so that the angle bracket faces behind the mirror plate, and an **Edmund Scientific Front Surface Mirror 204 X 254 mm G40,067** is hot glued onto it, without a wooden frame. The unfortunate thing about wooden frame borders is that they always come out well in the holgram around the reference beam. Mounting without a frame cleans that up.

The trio of solid steel posts hold the **Mirror Mount** up high extremely stably, with the **Mirror's** center along the optical axis determined by the centers of the **Holographic Plateholder,** the **Groundglass Projection Screen,** and the **Movie Projector.** This mirror's adjustment screws are locked in position and should not be adjusted during **Reference Beam Alignment.** The undiverged beam is attacking the **Plateholder** at the proper <u>altazimuthal angle</u> when it hits the center of a **Target Card** in the **Plateholder** and its reflection from the **Front Clear Glass** lands on the **Line Drawn on the Table to Denote the Optical Axis of the Object and Reference Beams.**

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* A legendary photographic scrapyard in Chicago, now defunct.

** This so-called **Mirror Stack** is one post with mirrors from both beam paths on it.

The **Jumbo Reference Beam Mirror** is just before the **Plateholder**. It consists of an **Edmund Scientific No. G85,206 406 X 406 mm Mirror** in a **Wooden Frame**, supported by sand filled pipes assembled together with **Kee Klamps**. The mounting framework is critically positioned on the table so that the **Mirror's** whole surface is used to deliver a 45 degree incident **Reference Beam** along the short side of a 30 by 40 cm hologram.

By the time the **Reference Beam** finally makes it to the **Plateholder** it has had the opportunity to pick up bullseyes from dust at every step of the way. The **Mirrors** should periodically be blown clean with the **Air Nozzle** from the **Compressed Air Supply**. Although there may be this "cosmetic noise", the **Reference Beam** is free from spurious reflections thanks to effective baffling and irissing, as evidenced by the observation (through a piece of Polaroid) of nothing more than a small spot issuing from the Spatial Filter looking back through all the **Mirrors** from the **Plateholder's** position.

2.5 Object Beam Path

2.5.1 Back at the Beamsplitter

The **Polarizing Cube** inside the **Newport Model 930-63** was reoriented to reflect the horizontal polarization upwards out of the unit, which becomes the **Reference Beam**, while the vertically polarized vector is transmitted straight through the box. No **Half-Wave Plate** is necessary in this beam as it travels parallel to the tabletop and preserves its vertical polarization orientation to interfere with the like-polarized reference beam.

2.5.2 Steering and Path Length Matching Mirrors

This **Object Beam** arrives at a **Newport Model 625A-2C** with an **A-2-1 Adapter** for a **10D10 Pyrex mirror with ER.1 Enhanced Aluminum Coating** on a **Model 45 Damped Rod** screwed into the Table. From here it is bounced to the **Lower Mirror** on the **Mirror Stack**, again a **Newport Model 625A-2C** with an **A-2-1 Adapter** for a **10D10 Pyrex Mirror with ER.1 Enhanced Aluminum Coating.** Yet a third **Newport Model 625A-2C** with an **A-2-1 Adapter for a 10D10 Pyrex mirror with ER.1 Enhanced Aluminum Coating** catches the beam and turns it about 90 degrees to aim it into the **Spatial Filter Before the Movie Projector.**

All these mirrors are necessary to path length match the **Object Beam** to the long throw of the **Reference Beam.** With both these beams traveling a combined path length of over eight meters, air currents become a crucial issue. Keeping the **Acoustical Isolation Panels** on during exposures is essential to keep the refractive index eddies under control.

2.5.3 Object Beam Spatial Filter

The light illuminating the **Movie Frame** should be nice and clean, so a **Newport Model 900 Spatial Filter with a 5X Microscope Objective with 50 micron Pinhole** is employed before the laser light goes into the **Movie Projector**. It is a tight fit here, so the **Spatial Filter** is attached to a **Newport Model 360-90 Angle Bracket** to squeeze it into place. Fine lateral tuning is accomplished by sliding the **Spatial Filter** on the **Angle Bracket**. The **Angle Bracket** is screwed onto a **Newport Model 340-C Rod Clamp** clamped onto a **Newport Model 45 Damped Rod** screwed directly into the **Tabletop**. It would be rude to slide this **Spatial Filter** down its **Mounting Post** to run undiverged laser light into the **Movie Projector**; but it is necessary for setting up the **One-Step Rainbow Shadowgram Quick and Dirty Setup**. Students are cautioned to leave its chassis in place, but remove the **Microscope Objective** and **Pinhole** instead, and leave them on the **Newport Model 360-90 Angle Bracket** so that they can find them when they replace them.

2.5.4 Movie Projector

There is no documentation for this **Burke & James 16 mm Home Movie Projector**, so its date of manufacture and anything else about its industrial heritage would be a greatly appreciated trivia answer. It dates from an era when photographic consumer items were cast out of iron, rather than molded by injection in plastic. In its original incarnation light from a **Projection Lamp** entered a hole on the left side of the casting, and a mirror pointed it forward to the **Film Gate**. The **Mirror in the Projector** was simply glued into the casting, but the thick **Brown Crackle Finish** was too lumpy, and the casting roughly unfinished, for this mounting method to work with the higher precision required for working with laser light. (Since **Projection Bulbs** are multi-filamented, irregularities would be smoothed out.) A **Daedal Miniature Straight Mount Model 2100** (although purchased from **Edmund Scientific** as their **Stock No. 33,502 with Mirror**) replaces that fixturing, for perfect alignment of the bright center of the **16 mm Film** along the **Plateholder's Optical** Axis in cooperation with the **Newport Model 625A-2C** before the **Object Beam Spatial Filter**.

The **Film Gate** is a simple stamped guide, heavily plated for low friction on the **Film**. Notice that as the **Projector** is viewed from the front, the **Film Gate** is not in line with the **Take-Up and Supply Reels**. It is in line with the center of the **Holographic Plateholder**. Holes are punched in it for the light to pass through and for the **Film Advance Claw** to latch onto a sprocket in the **Film**.

In ordinary motion-picture work, the **Film** is standing still during the projection time, then the **Motor** drives a mechanism that passes a **Shutter** between the **Light Source** and **Film**, pokes a **Mechanical Finger** through the slot in the **Film Gate**, which gets stuck in a **Sprocket-Hole**, yanks the **Film** downward quickly one frame, retracts, and the **Shutter** allows the Projection Light to pass through again. This jerky method of moving the **Film** through the **Gate** requires that there is a path with **Loops** in it to take up the tension; follow the markings cast into the **Projector Body** when loading the **Film**.

A continuously running **Motor** serviced the **Projector** in its original incarnation to run the film through at 16 frames per second, but nowadays the holographic application demands about one frame every minute. The modification by Ed Bennett to perform this rate included fixturing a new slower motor to drive the old film advance mechanism, with a cam and Micro-Switch equipped follower timing one full revolution or cycle of advance. Mark Bain (BFA 1991) supplied the **Jog Switch in a Spray Paint Can Top.**

Although it is always recommended to use pin-registered 35 mm movie film cameras and projectors, the image placement of this 50 year old consumer item was very consistent. If only all of holography were so easy!

2.5.5 The Projection Lens

There are two lenses* for the **Projector**, both made by the **Canon Camera Company** for their line of 35mm SLRs. For **Landscape** or **Horizontal** format, use the **50mm f/1.4**, as it blows up the horizontal side of the 16mm frame to approximately 15 inches.

The other lens, **35mm f/2.8**, is for **Portrait** mode, as it blows up the short vertical side to the full 15 inches height-wise. The horizontal dimension is about 20", so things in the periphery of the scene will be cropped when the transfer is made onto a 30 by 40 cm film oriented vertically, but the image of a face in this mode is as big as life!

Thanks to a **Newport Model No. 460XZ Translating Stage** the **Canon Lens** can be moved horizontally or vertically to center the projected image on the **Groundglass**. This can take care of small misaligments in the shooting stage. The micrometer knobs are under and to the side of the lens mount, and are awkward to get to, but are smooth-running once they are found.

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* **HISTORY OF THE PROJECTION LENS:** The lens that came originally with the projector was a 2" focal length f/2.8, of the same vintage as the projector. Internal reflections from non-anti-reflection coated elements gave ghost images that were annoying to say the least. Then we were loaned a **2" f/1.4 Bell & Howell Projector Lens**, and it had a better design and had no ghost images but there were now a seies of concentric interferometric bands across the screen, visible with no film in the projector and subtly so in the highlights of the film.

A gift of $400 was made to the **Holography Department** from Absolute Graphics courtesy of the largesse of Mel Theobald (MFA 1960). It was thought that a brand-new **zoom lens** would answer the need for a clean image and would be able to vary the size of the projected image, for horizontal and vertical formats, from wallet-sized to 30 by 40 cm. Zoom lenses of various focal lengths ranges, f/stops and manufacturers were shuttled back and forth from **Central Camera**, all exhibiting the fringes caused by internal reflections from their many lens elements and AR-coatings not tuned in for the 633nm He-Ne Laser wavelength.

Finally a **Canon 50mm f/1.4** was brought back to fill the need quickly for a normal optic, and it had fewer elements and better AR coatings for a blemish-free image. Later the **35mm slightly wide-angle lens** was bought to serve as the full 30 by 40 portrait format lens.

The projector lens can be translated back and forth by remote control by pushing the button on the top of the **Newport Model No. 846HP High Power Shutter Box*** on the right side of the **Holographic Filmholder**. This powers the **Oriel Motor Mike** which drives the **Newport Model 430 Translation Stage**. The motor runs very slowly, so the students have to be patient when watching the image go in and out of focus.

Sometimes they may even have to stick their heads through the **Filmholder** aperture to get a close enough look. It is rewarding, as one can see distinctly when the image is in focus, as the dark interference bands around each edge disappear.

2.5.6 Groundglass Screen

A piece of double-strength window glass lightly sand-blasted is used as a back-projection screen. Contrary to conventional Ph.D wisdom, groundglass does not depolarize laser light. Simply rotate a polarizing filter in front of a glowing screen and see the results. Diffuse reflection scrambles the polarization vectors, while diffuse transmission not necessarily so.

Other types of backlit screens may have better viewing angle, but the sand-blasting on ours gives enough lateral emissions for the peripheries of a viewing zone defined by a 35 cm wide master 60 cm from the copy plate. Coarser gives wider viewing at the expense of resolution lost in speckle.

The **Groundglass Screen** is placed 60 centimeters from the **Plateholder** and is held in position by two **Newport PH-6 Postholders** with **1/2" Steel Rods** in them to clamp to two **1/2" Steel Rods** screwed into the sides of the **Wooden Frame of the Groundglass** with **M^3 Visual Research Laboratories Right Angle Clamps**. **Collars** on the **1/2" Steel Rods** ensure that the **Groundglass Screen** remains at the proper height to keep its center in line with the **Optical Axis of the Holographic Plateholder** in case it is ever removed. A third post holder, **Newport Model PH-2**, grabs a **Short 1/2" Steel Rod** screwed into the bottom of the **Groundglass Screen.** The ground side of the **Screen** is toward the **Holographic Plateholder** to avoid ghost images with back reflections from the flat side.

2.5.7 Holographic Plateholder

A wooden frame based on photographic **Contact Print Frame** technology (clear glass in front, spring-loaded pressure plate in back) is coupled to the chassis of a former **Dot-Matrix Computer Printer**. The printing engine was geared to move a hundredth of an inch per pulse, and the current state is to move 19 steps for each Holographic Sterogram Frame.

The film is sandwiched between a clear front glass and another glass painted black on the back to supress the recording of spurious holograms. Once in a while there is a trapped air bubble, but squeezing the glass-film-glass sandwich with all your might usually eliminates the film movement.

The travelling slit is made of spring steel, and slides in front of the glass of the **Filmholder**. It is removed from its carriage so that the entire film may be exposed when doing masters of objects or Rainbow Shadowgrams.

Attached by Velcro on either slide of the travelling slit are window shades, mounted vertically. They cover up the rest of the holographic film which isn't being exposed during a certain slit's exposure. Spring tension winds up one curtain as the slit travels while the other is being unwound. (A Dean Randazzo invention.)

We use an ordinary DPDT switch to change the direction of the slit, although conventional electrical engineering wisdom would say otherwise when it comes to stepper motors. With our **typical turntable rotation footage**, the **Slit** translates

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* The shutter guts were removed and replaced with a momentary on-off switch and a sliding DPDT switch, the perfect requiem for a pair of these worthless pieces of junk. Two of these things failed within a week after having come back from Newport for repairs. (A previous instructor had ordered them; I wouldn't be caught dead ordering garbage like this!) The reason they failed is that this bi-stable device depends on glorified rubber bands, O-rings, to flip its states. And they were just not put on right. Nor designed properly.

from left to right. Sometimes scene captures would be made outside of the studio, like from an "El" train, and there may be need to accomodate different object movement directions.

2.5.8 Baffles
are strategically placed all over the printer to make sure that the **Holographic Film** only sees a tiny spot in the **Reference Direction** and nothing other than the **Projected Movie Frame** in the **Object Direction**. No longer is there noise from spurious reflections off of optics thanks to 3 millimeter thick sheets of **Sintra Material** fastened to the table with **Angle Irons** and screws. The students are warned to not trying to take them down unless they plan to spend a couple of hours replacing them; their shadow casting positions' tolerances are really close to 100's of microns! (Half a millimeter, really!)

There is a **Baffle** around the **Laser** to channel off heat and **Garbage Light (Collateral Radiation)**. It insulates the **Reference Beam Path** from heat convection currents that mess with the **Refractive Index of the Air.**

There is a **Great Wall of China Baffle** that follows a curve that circumvents the **Spurious Reflections** from every other optic on the table ending up at the **Plateholder**, which terminates at the **Movie Projector**, where another **Baffle** squarely in front of it lets nothing but the **Image Light** through a square hole. A pair of **Sintra Chunks** describe a right angle in front of the **Newport Model 625A-6C** to to prevent illumination of the trio of **ThorLabs P14 Mounting Posts** which supports the **Daedal X5700 Mirror Mount** of the **Reference Beam.**

2.5.9 Beam Balance Ratio
We try to standardize on a particular reference beam reading, with attendant exposure time, developer and its time, and not worry about the object beam. A properly exposed movie film (actually for our purposes it is usually a stop overexposed from the manufacturer's recommended film speed for white light reflected projection!) will give a nice, bright, low noise easily transferable laser transmission hologram. The reason we do it this way is that it is very hard to read the object beam light, since in the case of portraits and computer graphics the background is usually black. Sometimes grossly overexposed movie footage will show a "blooming" effect around itself, and then the object beam intensity should be decreased, and compensate for the shorter exposure time by consulting the light meter chart.

There is a 5/8" post with a clip on top of it of just the right height so that when it is screwed into the hole in the center of the bottom of the **Holographic Filmholder** the **Light Meter Probe** is in the Exact Dead Center of the piece of film.

With both beams unblocked, shutter armed, projector plugged in, initial frame in film gate, focussed, (lens cap off!), slit adjusted to proper size, proper direction ascertained and moved to its starting postion, window shades attached, (both sides), exposure and settling times dialed in on Herman, the printer is ready to rumble. Usually the results are seen in less than two hours. If the **Master** is good, then it goes into the **Transfer Set Up.**

3. THE TRANSFER TABLE

The **TRANSFER TABLE** is to the **HOLOGRAPHIC STEREOGRAM PRINTER** as a photographic enlarger is to a photographic camera; they work as a team to produce the final image. A camera produces a photographic negative which has its tones reversed, and it needs to have them re-reversed to make the final, legible print. Although the **HOLOGRAPHIC STEREOGRAM PRINTER'S** output is laser-viewable, the final holographic print from the **TRANSFER TABLE** is white-light viewable. This is accomplished by projecting the real image of the **MASTER HOLOGRAM** from the **HOLOGRAPHIC STEREOGRAM PRINTER**, which is pseudoscopic, or space inverted, a spatial negative, onto a second holographic film, and irradiating it with its own reference beam to record a new hologram, using the image from the first as the object for the second.

The **SAIC HOLOGRAPHIC TRANSFER TABLE'S** primary function is to convert the first step, the **LASER TRANSMISSION MASTER HOLOGRAM** of the **TWO-STEP IMAGE PLANE HOLOGRAM** process, into a **WHITE LIGHT RECONSTRUCTING HOLOGRAM.** The two tables are tuned in to each other so that the maximum amount of production may be done with the minimum amount of resetting up.

The length of the **Reference Beam Path** is made as long as possible to flatten out the wavefront to approximate a <u>collimated beam</u>, useful for lowering aberrations in the **Real Image To Be Transferred**. The expanding beam traverses the **Transfer Table** 2 1/2 times, with the pathlength approximately <u>8</u> meters long*, >16X the length of the diagonal of the **Film Format**.

3.1 A TOUR OF THE TABLE

The foundation for the SAIC **HOLOGRAPHIC TRANSFER TABLE**, like its cohort, the **HOLOGRAPHIC STEREOGRAM PRINTER** is a **Newport Research Series Table Top Model No. RS-410-12**. The source of photons for this set up is the SAIC Holography Department's trusty **Spectra-Physics Model 124 Helium Neon Laser.**

3.1.1 BEAMSPLITTING

Beamsplitting chores are handled by an **MWK Industries Item 39AU2 Polarized Beamsplitter**, mounted on a **Newport Model MM-2 Mirror Mount** lying on its back, supported by a **Newport Model SP-4 Support Post** slid into a **Newport Model VPH-6 Post Holder** on a **Newport Sliding Base B-2** screwed into the **Isolation Table.**

To vary the ratio between the reference and object beams, a **Melles Griot 02 WRM 023 Mica Half-Wave Retardation Plate** sits in a **M^3 Visual Research Laboratories Rotating Mount**, bolted to the **Isolation Table** via a **Newport Model VPH-6 Post Holder** and **Steel Rod.** Jesus Lopez added a geared ring to the **Rotating Mount** and mounted its matching **Pinion Gear and DC Motor** on the stationary part of the **Mount.** These components came from a junked **Super-8 Movie Camera Zoom Lens.** It is controlled by a **Mouse** at the **West End** of the **Table**, and will allow the holographer to vary the **Beam Balance Ratio** by <u>Remote Control</u>.

Another **Melles Griot 02 WRM 023 Mica Half-Wave Retardation Plate** sits in a **M^3 Visual Research Laboratories Rotating Mount**, bolted to the **Table** via a **Newport Model VPH-6 Post Holder** and **Steel Rod** to orient the <u>Polarization Vector</u> of the beam reflected from the cleave inside the **Polarizing Beamsplitting Cube** to match that of the transmitted beam. This set up of discrete components works just as well as the 5 times more expensive **Newport 930-633 Beamsplitter/Attenuator** in the **Master Set Up.**

3.1.2 MASTER REPLAY BEAM PATH

The beam that projects the real image onto the **Copy Hologram** is the one reflected by the cleave in the **Polarizing Beamsplitting Cube.** It is aligned to be parallel to the **Tabletop** by the knobs on the underside of its platform, a **Newport Model MM-2 Mirror Mount**, and its alignment to the **Isolation Table's** edge is controlled by twisting the **Support Post** in its **Post Holder.**

3.1.3 HALF-WAVE PLATE

A **Melles Griot 02 WRM 023 Mica Half-Wave Retardation Plate** sits in a **M^3 Visual Research Laboratories Rotating Mount**, bolted to the **Table** via a **Newport Model PH-6 Post Holder, Steel Rod** and **Newport Model B-2 Sliding Base.** This unit is used to horizontally orient the **Master Replay Beam's Polarization Vector** for minimum woodgrain. It's easy to align the polarization vector properly by minimizing the reflection off the Glass by observing the garbage light on the wall.

3.1.4 SPATIAL FILTER

Beam cleaning is accomplished by a **Newport Model 900 Spatial Filter.** This **Spatial Filter** is attached to a **Newport Model 360-90 Angle Bracket** which is screwed into a **Newport Model 370-C Rod Clamp** whose pinion gear rides in the rack of a **Newport Model 75 Damped Rod.** This way all four holes in the base of the **Model 70** can be screwed into the **Tabletop** for the ultimate in stability, and the **Spatial Filter** can be slid tranversely to and fro on the **Angle Bracket** to be precisely situated in the center of the beam.

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* This explains the digits in the WL-828 logo you may see floating around the table.

The power of the magnetic micrometers on the **Spatial Filters** has been restored with **Radio Shack Magnets**. The ones we use are rectangular with a hole n them that fits nice and snug around the micrometer shaft. Now the **Pinholes** don't have the nasty habit of drooping out of alignment.

Switching to the cylindrical lens for **Rainbow Transfers** is accomplished simply by removing the **Pinhole** and **Microscope Objective** from this Spatial Filter, letting the undiverged beam pass through the chassis, and moving into position a **Melles Griot 25 mm Focal Length Cylindrical Lens** in a modified **Newport Model MM-2 Mirror Mount**. The rotating Part allows the stripe of laser light to be perfectly vertical; the tilting knobs let the stripe stay centered on the Master.

3.1.5 Iris Diaphragm
An **MWK Industries 66BNS2 Iris Assembly** limits garbage light from polluting the **Replay Beam**. Its aperture is centered on a properly aligned **Spatial Filter**, and should not be tampered with, because its usefulness as a guide would be compromised. It can be used to quickly check the tune of the **Spatial Filter**. It is attached to the **Isolation Table** with a **Newport Model PH-6 Post Holder, Steel Rod** and **Newport Model B-2 Sliding Base.**

3.1.6 Spread Replay Beam Mirrors
There are two of them, starting after the **Spatial Filter**, on the opposite side of the **Table** with a **Newport Model 625A-2C** on a **Newport Model 45 Damped Rod** screwed directly into the **Table**. Instead of the usual one or two inch mirror screwed into the recess in the **625**, an **Edmund Scientific Stock # 40,043 First Surface Mirror** (127 x 178 x 6 mm or 5 by 7 by 1/4 inches) is hot-glued to the **Mount**.

There is a special **Target Card** for aligning the undiverged and spread beams on this **Mirror** and its twin in the **Copy Reference Beam Path**. It is stored with other **Alignment Tools**, and is simply used by placing in front of the **5 x 7 Mirrors.**

Then the spreading beam is directed back toward the **Laser End of the Table** where it is incident upon an **Edmund Scientific Stock # 32,248 First Surface Mirror** (254 x 313 x 6 mm or 10 by 12 by 1/4 inches) hot-glued to a **Newport Model 625A-2C** on a **Newport Model 45 Damped Rod** screwed directly into the **Table**. This throws the beam back toward the other end of the **Isolation Table**, where it is intercepted about 2/3 of the way down by the

3.1.7 Master Plateholder
which supports the **Master Hologram to be Transferred**. This piece of equipment was designed and built here at SAIC by Steve Wolf (BFA 1988). The **Offitial Beam Height*** for this table is determined by the center of a 30 by 40cm piece of film in this **Holder.**

3.2 Copy Plate Reference Beam Path
3.2.1 Beamsplitter
The **Polarizing Cube** is oriented to transmit the horizontal polarization vector, which becomes the **Reference Beam Path for the Copy Hologram.** No **Half-Wave Plate** is necessary in this beam as it travels parallel to the tabletop and preserves its horizontal polarization orientation to interfere with the like-polarized light coming from the real image of the master hologram.

3.2.2 Steering and Path Length Matching Mirrors
This **Beam** then arrives at a **Newport Model 625A-2C** tucked in the corner of the **Transfer Table** with the **"Electric Mirror"** of the **DikroTek Fringe Stabilizer** mounted in it to send the beam to the opposite end of the **Table.**

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* Jesus Lopez marked a ruler with the beam heights that we have adopted for the tables. This beam height is predicated on the distance above the tabletop where the center of the **Master Hologram** is located. We have come to know and love it as he christened it, "The Offitial Ruler."

This **Mirror** is a half-inch square mounted on a speaker cone, which will compensate for component drift, table bowing, and slowly moving air currents when it is plugged into the **Fringe Stabilizer Control Box**. It does not seem to be necessary for the **Transmission-Type of Transfer**, either **Achromatic** or **Rainbow**, but may be essential for **Reflection Copies**. Without being plugged into its **Controller**, the **Mirror** is just as stable as the regular, non-electric type.

Before the **Beam** bounces off the rest of the **Copy Reference Beam Path Mirrors**, it must first be diverged by the

3.2.3 Copy Reference Beam Spatial Filter
The light acting as the **Copy Reference Beam** should be nice and clean, so a **Newport Model 900 Spatial Filter with a 5X Microscope Objective with 50 micron Pinhole** is employed after the **"Electric Mirror"**. The **Spatial Filter** is attached to a **Newport Model 360-90 Angle Bracket** screwed onto a **Newport Model 340-C Rod Clamp** clamped onto a **Newport Model 45 Damped Rod** screwed directly into the **Tabletop.**

The two **Spatial Filters** and all the components before them are permanently atached to the table, and should be left in those positions; adjustments to the **Transfer Set-up** are made by the components downbeam, except when changing the **Microscope Objectives**, and then some finagling of the **Spatial Filters** themselves may be in order.

3.2.4 Copy Reference Beam Mirrors Continued
The diverging light from the **Spatial Filter** travels to the opposite end of the **Table** to meet up with another **Newport Model 625A-2C** on a **Newport Model 45 Damped Rod** screwed directly into the **Table**, with an **Edmund Scientific Stock # 40,043 First Surface Mirror** (127 x 178 x 6 mm or 5 by 7 by 1/4 inches) hot-glued to the **Mount**, a twin to the one on the **Master Replay Beam Path**. From here it is bounced back to the **Laser End of the Table** where it is caught by **Edmund Scientific Stock # 32,248 First Surface Mirror** (254 x 313 x 6 mm or 10 by 12 by 1/4 inches) hot-glued to a **Newport Model 625A-2C** on a **Newport Model 45 Damped Rod** which is not screwed directly into the **Table**, but screwed onto a **Newport Model 200 Low-Profile, Heavy Duty Magnetic Base.** This is one of the few components on this **Table** which is not fastened directly, and that's because this piece needs to be flexible as its position is determined by the position of the **Copy Plate Holder**, the **Reference Angle** for it, and the attendant path-length-matching.

All these mirrors are necessary to path length match the **Object Beam** to the long throw of the **Reference Beam.** With both these beams traveling a combined path length of over a dozen meters, air currents become a crucial issue. Keeping the **Acoustical Isolation Panels** on during exposures is essential to keep the refractive index eddies under control.

3.2.5 Copy Plate Holder
There are either **8" by 10"** or **30 by 40 cm Wooden Plateholders** available to hold the **Holographic Film** rigidly during the exposure. They are supported by a pair of **Enco On-Off Magnetic Base Indicator Holders King Size Model 625-0360** in the usual Goal Post style, with the **30 by 40 cm Filmholder** resting on the **Isolation Tabletop**, and the **8" by 10" One** being aided by a **Short Rod** at its bottom clamped by a **Swivel Clamp** to a **Magnetic base with a Short 1/2" Diameter Rod** to prevent the **Filmholder** from swiveling around during the loading of the film operation and as an added measure of stability during the exposure. To fully stabilize the bigger **Plateholder** place a couple of **Magnetic Bases** on either side of the **Frame.**

The **Projection Groundglass to Holographic Filmholder Distance** in the **HOLOGRAPHIC STEREOGRAM PRINTER** is 60 centimeters. Throwing the real image out of **Master Holograms** in our system increases that distance a few centimeters, and that distance depends on whether the real image is flushed out by either a **Spatial Filter** or a **Cylindrical Lens.** When switching from **Open-Aperture or Achromatic Copies** to **Rainbow Copies** an adjustment in focus distance is necessary. This can be calculated using the Benton Math.

The real image of the master is focussed onto a **Groundglass** placed in the **Copy Plateholder.** The **Beam Balance Ratio** is adjusted, the exposure calculated, shot and processed. Success rate is >75%.

4. THE THESIS OF THIS PAPER

One of the highlights of the First ISDH is the seminal paper on **Benton Math**[2]. This one coupled with the follow up[3], are the basis for calculations that are necessary for the optimization of the holographic image.

For art students this is anathema. They aren't going to sit still for any of it. The equations are out of their reach, as well as most of the general population. Plus, what really is the concept of astigmatism. Most of the time everyone thinks of it as referring to the human eye, which really is a strange case, because it is an on-axis aberration. For lenses its realm is off-axis. The equations are not really all that important at this stage, just knowing the terms on more than a superficial one to be at least able to fill in a crossword puzzle.

Students of all disciplines and ages like demonstrations in the very real sense of the word; none of this virtual stuff, it's as unreal as TV! So it was decided to produce a series of experimental holograms to illustrate the aberrations that are picked up optically in every step of the way of the process as practiced at the School, as a service to the students.

4.1 Demonstrations of the Classical Aberrations

The classical aberrations of lenses need to be demonstrated before any sense can be made of the holographic ones. The equipment I utilize is a He-Ne laser*, a pair of low frequency gratings, and a 300 millimeter diameter condensing lens from an 8" by 10" photographic enlarger[4]. For those not as blessed with one as big as mine, the demonstrations can still be satisfying with the more common 6 incher of a 4 by 5 enlarger.

Most serious discussions[5] of the aberrations in the literature show some sort of ray diagram depicting the paraxial and marginal mismatching. (Wouldn't they be much more tangible if illustrated in even anaglyphic 3-D!**) They can become very much alive in the classroom by generating a multitude of rays diverging from a common point with a pair of crossed low-frequency gratings. The ones I use I recorded with a 5° intrabeam angle*** and this produces lots of usable higher orders to fill the aperture of the big lens.

If the zero order of the grating is incident normally to the center of the lens, the progress of *spherical aberration* on the output side is charted by passing a piece of groundglass or frosted plastic through the exiting rays. A piece of cardboard with a hole in it for an aperture shows how stopping down the lens eliminates the aberrant rays for a smaller image spot.

Rotating the lens so that the central ray is coming in off-axis produces the ray bundles that map out astigmatism and coma. Removing the laser and looking through the lens at a brick wall, a grid drawn on a blackboard, or the Giant Periodic Table of the Elements found in the typical science classroom shows distortion and curvature of field. It is especially important to have a lens larger than the intra-ocular distance so that the curvature of the image is perceived three-dimensionally, looking like it is mapped onto a sphere even though the object is a plane.

What effect do these aberrations have on an individual point of the object? To visualize this redo the demonstrations done with the crossed gratings but input the lens with the point source from a pinhole of a spatial filter. The halo of the spherically aberrated spot, the transformation from a spot to a glob at just a few angles off-axis shows the coma, while

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* A trusty old **Melles Griot LHP-171**, which has served me in good stead since 1983. The tube is still putting out 6mW, but it is on its fifth power supply! Why can't those things be made as good as the tubes? The one that I recently replaced lasted 13 months, just 30 days longer than its warranty period! And the manufacturer had no pity on my condition.

** Maybe if I ever publish my own Encyclopedia of Optics. But I leave it to one of you, the readers, to steal this great idea.

***. From my 1991 art piece, **The Orgasmatron**, where these types of gratings surround a **Jacob's Ladder** in a tower-like structure, dispersing the glow of the rising spark into ascending rainbows.

tilting the lens even more and passing the target through the output is a real crowd-pleaser as the sagittal and tangential foci are so far apart. Sometimes they are not even straight lines but curved, as distortion creeps in.

Some sort of white light point source can be used to demo chromatic aberration. A fiber optic illuminator is the slickest and most expensive, but a millimeter-sized hole in a piece of metal in front of a light bulb will serve nicely.

After the holography students have seen the classical aberrations demonstrated, they are presented with holograms of cleverly-constructed test subjects to isolate the aberrations.

4.2 A Tradition of Testing

The approach to teaching students at the SAIC is to demonstrate the physical operation of the equipment so that technique is secondary and calibrate the materials in front of them so that there is no waste of their film and time. They like the analytical approach, being Art and Technology Department students, preparing for the 21st century.

Right from the first day of class they are exposed to Exposure and Development tests on Densiyuk style holograms of the **Standard Single Beam Reflection Test Object**, a silver spray-painted* waffle iron mold. This object presents a not very deep texture which is homogenous throughout the exposure test quadrants. Plus it's fun to look at the pseudoscopic side because it then looks like the waffle. The holographic plate sits on three ball bearings glued onto the waffle iron, and a piece of cardboard the size of the holographic plate is laid on top of it.

The cardboard is a test exposure mask. One of its quadrants had been cut away, so that four different exposures can be made on the plate as the masking card is rotated between them.

A pair of holographic plates are exposed to a logarithmic series of exposures, developed side by side in our standard developer[6], and then one is bleached in a solvent bleach[7] while the other in a rehalogenating one[8]. Simply by choosing the proper developer-bleach-exposure combination, the holographer can generate any color from the exact laser replay to a color approximately 150 nm shorter.

4.3 Laser Transmission Mastering

An **Exposure Chart** to use with the Holography Department's **S & M**'s SUPERSENSITIVE PHOTO METER DARKROOM MODEL A-3** was compiled by students many years ago. Recent testing has shown that if there is a reading of 15 on the **3 Scale**, exposure time would be 30". And other tests showed that a 30 on the **3 Scale** meant 15" exposure. Which makes perfect sense, since 30 on the **3 Scale** is twice as much light as 15, so the exposure time would have to be one-half the time. And 45" was the best exposure when a 10 on the **3 Scale** was read.

Notice that 15 x 30 and 30 x 15 and 10 x 45 all = 450. This number is our **Holographic Film Speed Number**, not unlike the **ASA/ISO numbers** for photography.

Except that this number is simpler to use. Simply measure the incident laser flux at the **Holographic Film Plane** with the **Meter**, divide the number on the **3 Scale** into 450. The quotient will be the exposure time in seconds for **Agfa Holotest 8E75HD Film**, developed for 2 minutes at **75F in CWC2 Developer** and bleached in the **Copper Sulfate Bleach.**

For the One Step Rainbow Shadowgram set up an exposure test series is also run to find the dynamic range of the holographic film, which is all-important for color blending by multiple exposures.
Then a color palette is generated by slit movement.

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* Krylon Bright Slver No.1401. The "pigments" are tiny flecks of aluminum powder, which help preserve the polariztion of the reflected light.

** Science & Mechanics Instruments, 805 East 59th Street, Brooklyn, NY 11234.

Once the students see how cool this holographic silk-screening is they get caught up in the fun of the analytical process, devising their own experiments and creating some interesting pieces via in-process discovery.

4.4 Back to the Thesis of this Paper

By this stage the advanced holography student has become familiar with the characteristics of the holographic image and process and can observe them with a trained and discriminating eye. So they are not going to be bothered by a holographic test object designed to illustrate the holographic aberrations, especially if it will help them understand what is being transformed in their own images. (Plus they have a few more new terms to drop at holographic cocktail parties.)

The holographic image in our process becomes aberrated;

1.) When the real image is projected out of the master by a replay beam that is not the exact conjugate of the recording beam;

2.) The copy hologram is replayed by a beam that is not the conjugate of the beam used to record it.

To see where an image point ends up in the process means applying the **Benton Equations** twice. The aberration produced by recording a hologram with a reference spot 8 meters behind, but then re-illuminating it from the opposite side to conjure up the real image with a beam that is not convergent at the original reference site produces for example a separation of the two astigmatic foci of 28 mm.

Then this aberrated spot is recorded by the copy plate, and it too is replayed by a source that is not anywhere near the same as the one used in recording it. It aberrates the aberrations.

The first exercise in understanding the role of the reference distance in the replay of the master hologram is by holding a master, and standing close to the beamspreader used to illuminate the hologram, examine the magnification in the virtual image by walking away from the replay point source. At the end of the line, (about 8 meters down the hallway) a comparison of the virtual image with real object can be made.

4.4.1 Test Object

A grid of Formaline tape on 5 centimeter centers applied to the groundglass would give interesting observations of distortion and curvature of field in the final hologram. A groundglass inserted in the copy filmholder would slide through the sagital and tangential foci to illustrate astigmatism as the horizontal and vertical lines wold focus at different distances. Some **USAF Resolution Targets** could be placed at various spots on the groundglass to analyze resolving power loss due to astigmatism.

The resolution of the rainbow hologram with its horizontal slit could be compared to that of the full aperture utilized in the Achromatic copy. The master could be masked off to transfer only one .190" wide single film frame to see the resolution available in one stereogram frame.

To see the effect of these double aberrations on image points, a grid of laser beam-sized spots could be generated by taking the lenses out of the projector and multiplying the unspread beam with a pair of low-frequency gratings. Just like in the lens demo, the gratings generate a gridwork of spots on the groundglass. Then dimensional changes of these spots throughout the field could be studied.

Rainbow and pseudo-achromatic[9] copies would be made. Photographic paper* could be put in the copy plate holder, so that a two-dimensional record of the target could be studied. For the eye adapts to the aberrations of the holographic image (to some degree) in space, but here it is caught or frozen for dissection.

But alas and alack[10], these neat ideas did not get turned into reality for a variety of reasons, quality CWS time, budget of materals and time, the general plight of the underpaid Adjunct Professor, etc. Maybe my erstwhile successor will perform these experiments.

4.5 Tests that We Did Run

Although our system is a flat master to a flat copy, our stereography capture method entails placing the subject on a turntable and filming with a stationary camera. The turntable we inherited rotates at a glacier-like rate. For the optimal stereo effect, we need to generate an angular baseline cinematographically which is analogous to the intra-ocular distance of the typical human observer. With a fixed rate of rotation, the intra-ocular with time distance increases by decreasing camera filming rates. Too high of a film speed would produce the synthetic intra-oculars too close, so that the final hologram would look flat as a photograph. Too far apart, the effect would be hyper-stereoscopic, and the observer would have the impression of looking at a toy rather than a similar to life size human being.

To calibrate the method we did a series of test shots of a subject** on the turntable, and varied the filming rate of the **SAIC Holography Department Bolex H-16** from its highest to lowest speeds, 64 frames per second to 12 fps. Because of the really slow turntable rate, the slowest filming rate worked well.

What is the true intra-ocular distance of the standard observer? Conventional stereoscopic wisdom usually give 65 mm (2½"), and trying to survey a class of students showed how hard it is to really measure that distance. The reason why we needed to know that is to figure which two film frames are being fused into the stereo scene. Greg Fister (BFA 1993, MFA 1998) decided to generate a sequence of movie frames that were simply the numbers 1 through 87 and turn them into a stereogram.

As the final rainbow hologram is observed with one eye, it counts up or down depending on which direction you holo-dance. But even with a cyclopean view, there were usually two numbers seen simultaneously. Only when the eye was at the position of the slit of the master was only one number apparent to one eye. Then the other was opened and a second number appeared.

For most people this number was 14 different, but it varied from 12 to 17. There wasn't a really good correlation betwen size of person and the intra-ocular count. But it did give an idea of the stereogram baseline.

Another observation concerning this hologram was that single numbers were apparent only when it was replayed with sunlight. Because of our cramped quarters, the reference distance for the replay of the copies was less than 2 meters. Each vertical slit of the master was so aberrated that it bled into its neighbor. Another good demonstration of why the replay lights need to be as far away as possible in a viewing space.

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* Kodak Panalure Paper would be suitable for Helium Neon lasers. This photographic paper is the only panchromatic printng paper, used for making black and white prints in correct grey reproduction from color negatives. Typical photographic papers' spectral response is simply blue and maybe a little green. Orangey safelights are used with conventional papers, but Panalure cannot tolerate even the weak green ones found in the red laser lab. Total darkness is a must, and makes working with it a more nerve-wracking experience in the holo lab than normal.

** Which turned out to be the author. After this session I was slightly vertiginious, something that happens with encroaching middle-age. I remember my father explaining that he couldn't go on the rides with us kids because they made him sick; I thought that if I got so old that carnival rides were no longer fun life would not be worth living.

5. Acknowledgements

Dean Randazzo for coming up with the idea to make a holographic stereogram printer while he was at the School as a Graduate Student, Ed Bennett for designing the Mark I and II controllers, Matt Deschner for assembling the controllers and very patiently running countless tests to peak the system, Bill Molteni for coming out and giving us some sorely-needed pointers, Matt Schreiber and Kurt Lawson for all the energy expended in the big move, Greg Fister for computer rendering some test objects and keeping the evaluation program alive, and of course Jesus Lopez, for living in the lab to make it perfect, and Dan Miller for keeping up the tradition and knowing where everything is.

6. References

1. **M[3] Visual Research Lab**, 2124 West Irving Park Road, Chicago, IL 60618-3924.

2. Benton, S. A., "The Mathematical Optics of White-Light Transmission Holograms," *Proceedings of the First International Symposium on Display Holography*, T.H. Jeong, Ed., Volume 1, pp 5-14, Holography Workshops, Lake Forest College, 1982

3. Benton, S. A., "Wave-Front Aberrations: Their Effects in White-Light Transmission Holograms," *Proceeding of the Second International Symposium on Display Holography*, T.H. Jeong, Ed., pp.167-175, Holography Workshops, Lake Forest College, 1985)

4 . Purchased from Dave Phillips, 1234 West Washington Boulevard, Chicago, IL 60607, just down the street from that wicked holography museum, Gallery 1134. He's got tons of photographic cast-offs, his specialty being Kodak Versamat processing machines.

5. See for instance William H. Price, "The Photographic Lens", *Scientific American*, August 1976, pp.72-83. Melles Griot and Newport Catalogs in various editions of their catalogs have borrowed heavily from Optics by Hecht and Zajac. I myself have cleverly reworked diagrams from a variety of sources and compiled them in Optics for Artists, available from M[3] Visual Research Laboratories.

6. D. J. Cooke and A. A. Ward, "Reflection-Hologram Processing for High Efficiency in Silver-Halide Emulsions," *Applied Optics* 23, 973 (1984).

7. Walter Spierings, "'Pyrochrome' Processing Yields Color-Controlled Results with Silver-Halide Materials", *holosphere*, Volume 10, Numbers 7 and 8, p.1, (1981)

8. Jeff Blythe, "A Novel Approach to Colour Processing", *Wavefront*, Volume 2, Number 3, p.23 (1987).

9. My term for the type of hologram that was begging for a name in the Holography Handbook. Did I win? Who did?

10. I've been up too late! I'm quoting Shakespeare! (I think)