holosphere
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Hologram Cylinders, 4 Meters Long, Display Rare Objects Without Risk

ANN ARBOR, MI—An antique guitar appears through the window of what appears to be an early television set. As the viewer rotates a pair of dials, the guitar rotates 360°, offering a continuous view as it turns. This is not an electronic image though, but an optical one produced through an ambitious application of cylindrical holography.

Made by a team of holographers at the Environmental Research Institute of Michigan (ERIM) in conjunction with the University of Michigan School of Music, it is a successful attempt to use holographic reproductions of rare objects for educational purposes. Supported by a grant from the Exxon Educational Foundation, the holograms were designed and executed by Juris Upatnieks, Emmett Leith, C.D. Leonard and E.J. Martilla from 1973 to 1975. The objects, rare musical instruments from the School of Music's Sterns Collection, were supplied through Prof. William Malm of the school who was project director.

This story is adapted from the papers "Archival Storage of Three-Dimensional Images" by Upatnieks, Leonard and Matilla, which was delivered at the International Optical Computing Conference of the Computer Society of the Institute of Electrical and Electronic Engineers, 1975, and published in the conference digest and the report "360° Hologram Camera and Display System for Educational Use," published by Upatnieks in 1975 through ERIM.

The question might be asked as to why holograms should be used instead of slides or the original objects when studies include the examination of physical objects. The answer is that holograms have properties and realism not attainable with slides and have some advantages over real objects, too. The hologram recreates the object as a realistic image in three dimensions and of exactly the same size as the original. The 360° hologram, developed in the mid-1960's by Hioki, Suzuki, T.H. Jeong, P. Ruddle and A. Luckett shows the object from all sides in the horizontal plane and over some range in perspective in the vertical direction. The recorded object can be examined in detail with a magnifier or microscope to examine its fine features.

As compared to original objects, holograms have the advantage of allowing an ideal means of viewing and examining instruments, sculptures, or other items that might be one of a kind or are valuable. The hologram, which is recorded on film, can be stored compactly and transported from place to place. In contrast, original objects require appropriate display cases, special handling, and, of course, are not as easily changed as the film in a viewer. Even storage in cabinets is more difficult with actual objects than with film. Greater opportunity for study will be possible using a holographic library of objects which might otherwise be kept under lock and key in comparatively few institutions.

For holograms to be useful in education Malm and the ERIM team decided that images must be presentable both to individuals, as in microfilm viewers, and to larger groups as in classrooms. Holograms naturally lend themselves to individual viewing but are not as readily usable for group presentation. Therefore a projector that displays hologram images on a two-dimensional screen was selected as an option for providing group participation. Such projections are two-dimensional, but the perspective shown can be changed horizontally and vertically.

The project thus became tripartite: to construct a camera and holograms, a hologram viewer and a projector. All three goals were achieved, and the cylindrical holograms turned out to be the largest ever made.

The Camera and Recording System

The conceptual arrangement for the camera is shown in Figure 1. In the actual camera nine object beams were used.

The camera size and configuration was the result of a compromise between the various desirable properties and the possibility of achieving them. It was decided to construct a cylindrical hologram film holder 120 cm in size and to use film 24 cm wide. This size could accomodate objects up to 100 cm long and about 40 cm high and wide. Since the hologram is all around the object a 360° change in perspective is possible horizontally and about a 20° change in the vertical direction, although this latter number is dependent upon the object to film distance and varies across the hologram.

The assembled camera is shown in Figure 2 with various components such as mirrors, beamsplitters, lenses and diffusers mounted on its edges. The film holder consists of an upper and lower ring with a 120 cm diameter groove in each ring to hold the film. The film is placed in these grooves and is pulled past the rollers and is supported only at the edges. The two rings are held apart by a number of spacers bolted between the rings.

The reference beam comes through a lens-pinhole assembly on axis of the cylindrical film and about 45 cm above the top of

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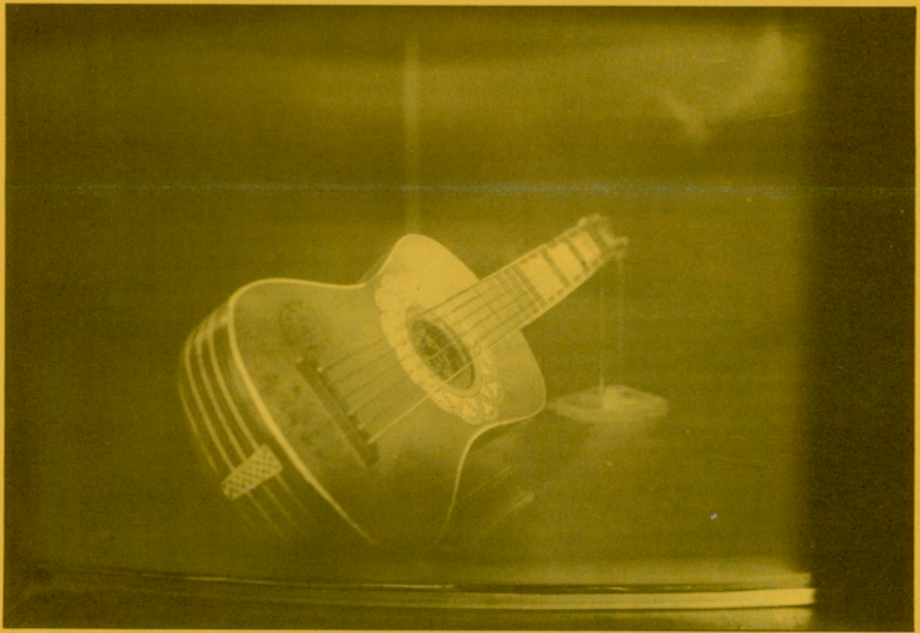

As though in a case, *a hologram of an antique guitar stretches back from the display window. One of eight musical instruments from the University of Michigan's Sterns collection, the instruments were holographed in a project to demonstrate the usefulness of holography in showing three-dimensional images of precious objects to those who cannot see the actual objects. Dials on the unit enable the viewer to rotate the image 360° for a full view of the instrument. Note that the dimensionality in this photo is highlighted by the depth of field of the camera lens, leaving either end of the guitar slightly out of focus.*

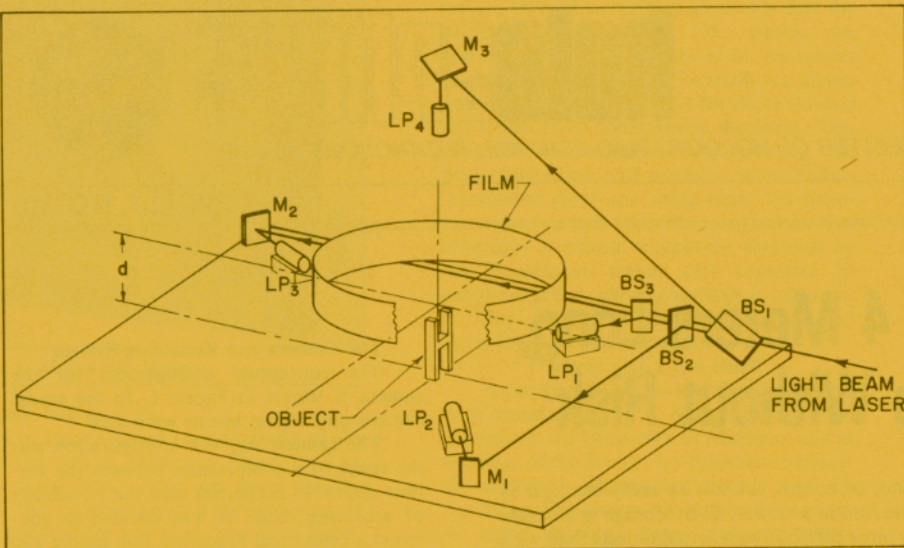

Figure 1. *Conceptual arrangement for the hologram camera.*

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the hologram film. The lens-pinhole assembly and a mirror are mounted on a tripod support attached to the top ring of the film holder. To get the extremely wide-angle spread of the reference beam, a miscroscope objective having a numerical aperture of 0.85 was used with a 25 micrometer diameter pin hole made from a 1 micrometer thick gold foil. Ordinary pinholes were not suitable because the material thickness prevented light from reaching the film at the required extreme angles.

Concerning the object beams, ground glass diffusers were used to spread the beams rather than the conventional lens-pinhole assemblies. Two considerations necessitated the choice: due to the size of the object and its proximity to a lens-pinhole on the edge of the camera, a beam could not be sufficiently spread out by a lens, and the large number of beams needed would make the cost of purchasing a sufficient number of lens-pinhole assemblies prohibitive. Also the table stability was such that keeping these lens-pinhole assemblies in alignment would be difficult.

The whole assembly was mounted on a 1.2 x 2.4 meter granite table on air suspension to isolate it from ground vibrations. The film holder and hologram recording assembly were enclosed completely during exposure to minimize air drifts and temperature changes in the recording setup. The laser, an Argon ion, Spectra-Physics Model 165, was located in an adjoining room and the green 514.5 nanometer wavelength line, with etalon to increase coherence length, provided the light.

The need for a coherence length of two meters provided one reason for the choice of an argon laser, which had a power output of 600-900mw. Also, the eye is more sensitive to green than other colors, which leads to improved visibility of the image during reconstruction. Lastly, the blue, 488 nanometer wavelength line would prove useful during hologram projection.

Film stability in the camera was excellent as far as mechanical disturbances were concerned, but proved highly unstable due to temperature and humidity changes in the camera. To hold the film stable to within one-

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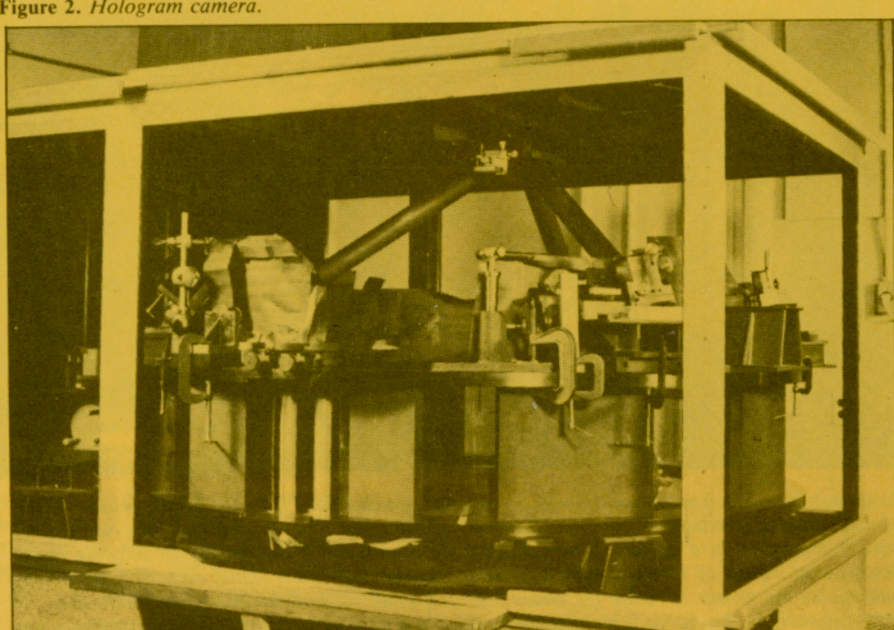
Figure 2. *Hologram camera.*



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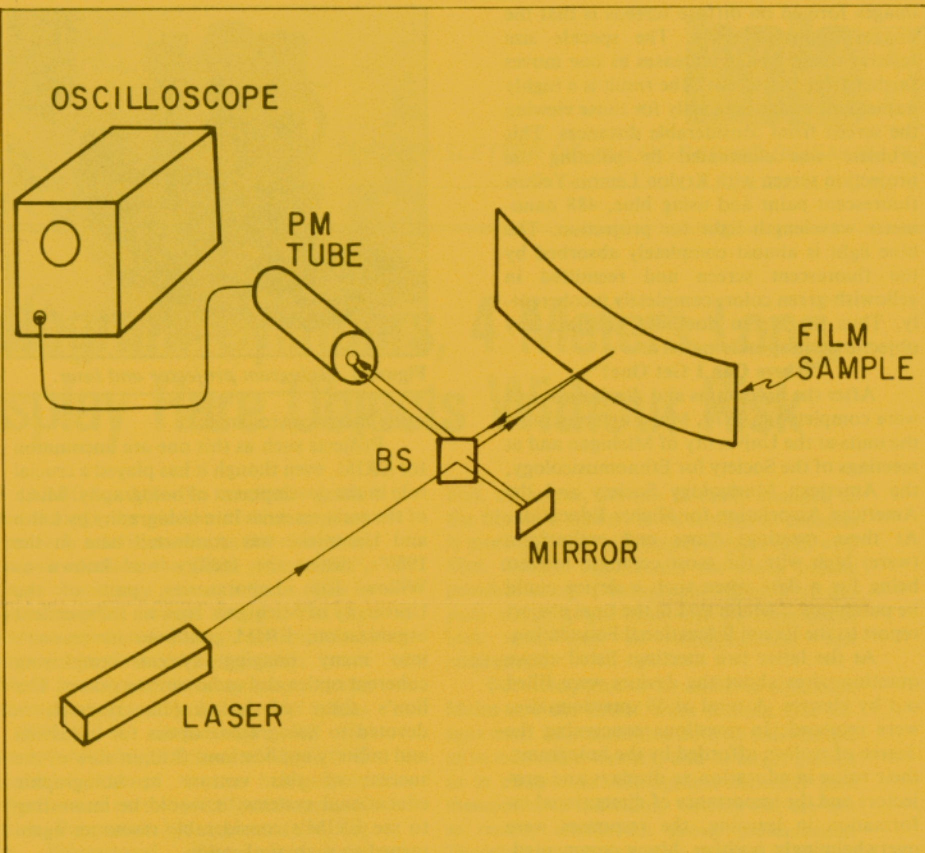

Figure 3. *Conceptual arrangement for film stability monitor.*

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half wavelength of light during the 60-90 second exposure, an estimated temperature stability of 1/1//°C was needed. Extreme precautions were necessary to achieve the needed film stability and a real-time film stability monitor was added to the camera.

Figure 3 shows the stability monitor. A short section of the 24 cm hologram film was mounted on the outside of the film ring structure. A helium-neon laser beam was reflected off its surface and combined with a stable reference beam in a Michelson interferometer arrangement. The resulting fringe pattern was projected onto a photomultiplier tube so that its output current varied as a fringe would move across its entrance slit. The photomultiplier output was connected to an oscilloscope and both slow, temperature-caused stability shift and fast, audio-frequency caused film instabilities, could be observed on the oscilloscope in an adjoining room. The exposure and lasers were controlled from this room. With this arrangement real-time film stability measurements were possible, although the measurements were of a sample film, not the one being exposed, and also just one point could be monitored this way. The data turned out to be very useful and based on this data stable holograms could be made.

With the film stability monitor the holographers observed that the film was always unstable immediately after the hologram recording setup was completed and covers placed on the table. A very gradual decrease could be observed that usually dropped to one-half wave-length per minute in about 45 to 90 minutes. A stable condition was reached, however, only when the table surface was at the same temperature as the room air or not more than 1°F higher than room temperature. Stability also was not reached on very humid days.

The usual procedure for film recordings was:

- obtain room temperature 0°-1°F above table temperature;
- obtain relative humidity below approximately 70 per cent;
- insert film and wait 45 minutes and
- expose when film stability is one half wavelength per minute or better.

The exposed film was developed in the usual fashion (i.e. Kodak D-19 Developer, stop bath, fixer, etc.) and then bleached.

Although the primary purpose for bleaching was to improve diffraction efficiency, it also served to mitigate two other effects. Due to the proximity of the field to the sharp edge in the entrance aperture of the lens and subsequent spatial filter, a coarse fringe pattern remained across the reference beam, causing two to three dark fringes across the film height. In addition, several dark spots a few inches in diameter in the reference beam at the film plane were observed. These were caused by dust particles and/or lens defects on the glass surfaces very close to the point focus of the microscope objective. Neither of these problems occur in ordinary holographic setups where the center portion of the field is used and the lenses have longer focal lengths.

The bleaching technique used was an iodine solution in conjunction with hardener. As employed, overexposed areas of the hologram were not completely bleached thus having the effect of making the effective exposure more equal across the hologram.

Significant Recording Data

Film Diameter:	1.2 meters
Film Length:	4 meters
Film Width:	24 cm
Type of Emulsion:	Kodak 649F, with 8 mil thick Estar base
Laser:	Spectra-Physics Model 165-03 with etalon, wavelength 514.5 nm, power to 900mW
Exposure Time:	60-90 seconds
Laser-Energy/ Exposure:	42 Joules
Number of object beams:	9

Hologram Viewer

To keep the viewer small and taking into account its intended use, namely, viewing by one individual, it was decided that displaying a 27cm length of film at a time would be satisfactory. The rest of the film was stored on two spools, one at each end of the viewer. A necessary requirement for distortionless image formation by holograms is that both the shape of the hologram and its illuminating beam must be the same as in the recording process. For this reason, it is necessary to hold the film on a 60 cm radius guide and the light source had to be about 73 cm from the edge of the film and above it. To make the viewer more compact two mirrors were mounted in the box to fold the path length. A cross-sectional view of the viewer is

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Figure 4. *Cross-sectional view of viewer.*

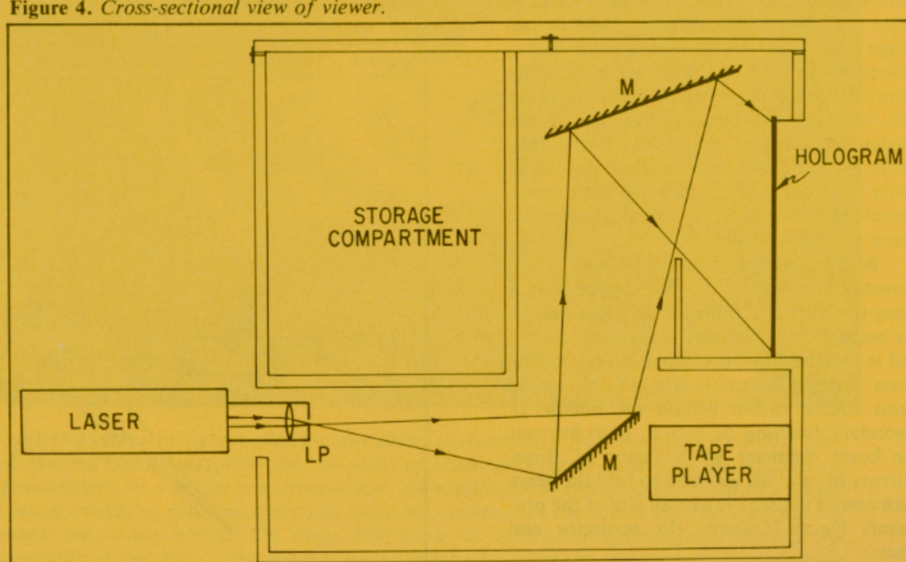

Figure 5. *Hologram viewer.*

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shown in Figure 4 and a photograph of the completed unit is shown in Figure 5. Two knobs in the front of the unit move the film across the viewing area. Approximately 16 meters of film for a total of four, four-meter-long holograms can be accomodated on the spools.

For illuminating, a source of at least 10mW of green light is needed. This is provided by an American Laser Corp. Model 64 air-cooled Argon ion laser having a wavelength-selector assembly. The laser is portable and can operate from an ordinary 115V household electric outlet. For use with the viewer a lens-pinhole assembly is attached to the laser to expand the beam and the laser is simply placed against the back side of the viewer.

Underneath the viewing area a stereo tape play-back unit is mounted. Tape cassettes with appropriate explanation of the objects being seen or demonstration of their sound can be added to provide a complete visual and audio demonstration of the instrument.

Hologram Projector

The hologram projector uses the same film as the viewer. A cross-sectional view of the projector is shown in Figure 6. The hologram is at the right and is illuminated by a small diameter laser beam, about 7 mm. Opposite the illuminated area of the hologram is an imaging lens that projects the virtual image formed by the hologram onto a screen. The lens and beam move together up or down so that the lens is always opposite the illuminated section of the hologram.

The image formed by the hologram is three-dimensional and is the same size as or larger than the original object. The lens can image only one plane exactly and has a limited depth of focus. The image therefore shows a limited depth of the scene in focus and lenses of different focal length are needed to select other planes. Thus, four lenses mounted on a turret so that any can be easily used were included. Since these lenses operate at f-30 or more, simple single-element lenses proved satisfactory.

Beam steering is achieved by lens L_1 and movable mirror M_1. As the mirror moves along the direction of the incident laser beam, the beam passes through the negative Lens L_1 and is deflected in the desired direction. The beam appears to rotate around the virtual point source shown behind the mirror. A secondary function of lens L_1 is to increase the beam diameter by a factor of three. Mirrors M_2 and M_3 are used to fold the beam path and to reduce the overall size of the projector. Figure 7 shows the projector and laser.

An undesirable feature of coherent images formed on diffuse screens is that the images appear speckly. The speckle size relative to the image increases as one moves farther from the screen. The result is a highly unpleasant image especially for those viewing the screen from considerable distances. This problem was eliminated by painting the projection screen with Krylon Lemon-Yellow fluorescent paint and using blue, 488 nanometer wavelength light for projection. The blue light is almost completely absorbed by the fluorescent screen and reemitted in yellowish-green color, completely incoherently. Thus the screen does not generate any objectionable speckle pattern.

"Where Can I Get One?'

After the holograms and display systems were completed in 1974, Malm demonstrated the units at the University of Michigan and at meetings of the Society for Ethnomusicology, the American Musicology Society and the American Association for Higher Education. At these meetings "awe and enthusiasm (were) high with the most common request being for a date when such a device could be purchased," Malm said in the final project report to the Exxon Educational Foundation.

At the latter two meetings listed above questionnaires about the devices were filled out by viewers. A total of 69 questionnaires were returned. In questions concerning the degree of realism afforded by the holograms, their value in education as displays and projectors and the importance of dimensional information in learning, the responses were overwhelmingly positive. Many commented, however, on the monochromaticity of the images, saying natural color would be more useful, especially in objects such as art works, Malm found (for additional reading, see "Holograms as a Library Resource" by Malm in Notes magazine, V. 32, No. 4, June 1976).

It appears that if holograms of rare objects useful in education were made available their use and demand would be widespread, judging from the responses of educators. The cost of the viewers is currently a concern but considerable decreases in cost are possible. Initially, viewers with laser light sources might be available only in libraries where several viewers could be operated from a single laser. This type of arrangement could reduce the laser cost per viewer from $5,000 in the present model to $260 per viewer for 35 viewers operating from a single laser. It might also be possible to build inexpensive viewers with somewhat reduced image resolution, using mercury arc lamps.

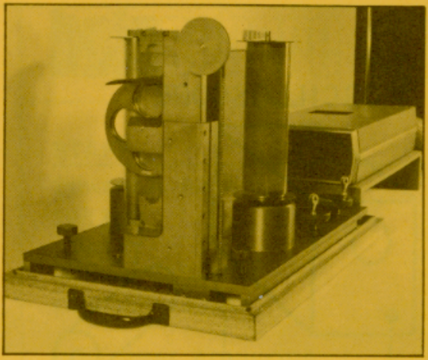

Figure 7. *Hologram projector and laser.*

Projects such as this one are uncommon for ERIM, even though it has played a crucial role in the development of holography. Much of the early research into holography by Leith and Upatnieks was conducted here in the 1960's, when the facility was known as Willow Run Laboratories, part of the University of Michigan. Now an independent organization, ERIM continues its research into many imaging systems employing coherent optics and radar among others. The lion's share of holographic research is devoted to holographic optics for industrial and military applications. Still, in view of the success of this venture in holographic educational systems, it would be interesting to see ERIM's considerable resources again turned to such application.

To Our Readers

Effective December 1, 1978, annual subscription rates for *holosphere* will be lowered from $45 to $25 domestic and from $55 to $35 foreign. Rates for members of the Museum of Holography are unchanged.

Also, in last month's story on the Isetan exhibition of holography, Tokyo, three holograms were not credited, and one was incorrectly credited. On page five are "Series of Six," by Randy James (top) and "Circle, Triangle, Square" by Shunsuke Mitamura (middle). The two column photograph in the center of page four is "Crazy Scope" by Kohei Suguira and Kazuo Okazaki. "Fossil of Light A-E" by Hiroyuki Kaji is on page six. And "Table Top" by Nick Phillips on page 5 is a reflection, not a transmission, hologram.

Figure 6. *Cross-sectional view of projector.*