The Lenkurt DEMODULATOR

FEBRUARY 1970

HOLOGRAPHY

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Holography, from the Greek root *holos* meaning whole, is a picture making process that captures the three-dimensional aspects of an object, rather than the flat, fixed-viewpoint of conventional photography.

In holography, three-dimensional images are formed from two-dimensional photographic negatives. In the recording process, a coherent wave source is split into two parts (Figure 1). Half the source (reference wave) strikes the holographic plate directly. The other half (object wave) illuminates the object to be recorded. Each point on the object reflects light onto the holographic plate. Having traveled different paths, the two waves are no longer in phase, and therefore reinforce or cancel each other as they converge on the holographic plate – producing an interference pattern (Figure 2). There is a unique interference pattern recorded over the entire holographic plate, for each point on the object.

Laser light is the most commonly used coherent source, but illumination may also be accomplished with electron waves, X-rays, microwaves, and acoustic waves.

Once the holographic plate has been exposed and processed, it is capable of reconstructing the original three-dimensional object. Reconstruction is accomplished by illuminating the hologram with the same frequency reference wave used for recording. Since the hologram records all the information that the object wave contains, the reconstructed image will display this information – the size and shape of the object; the brightness of every point on the object; and the position of the object in space, from all angles that are intercepted by the holographic plate during the recording process.

Basically, a hologram is a recording of two coherent waves. When the hologram is illuminated with one wave, the other wave is simultaneously reconstructed.

There are two fundamental types of hologram – transmission and reflection. In a darkened room, transmission holograms are illuminated from behind with monochromatic light (one color). Reflection holograms, however, with their built-in filters are illuminated with white light (all colors) from the side where the viewer is standing, so

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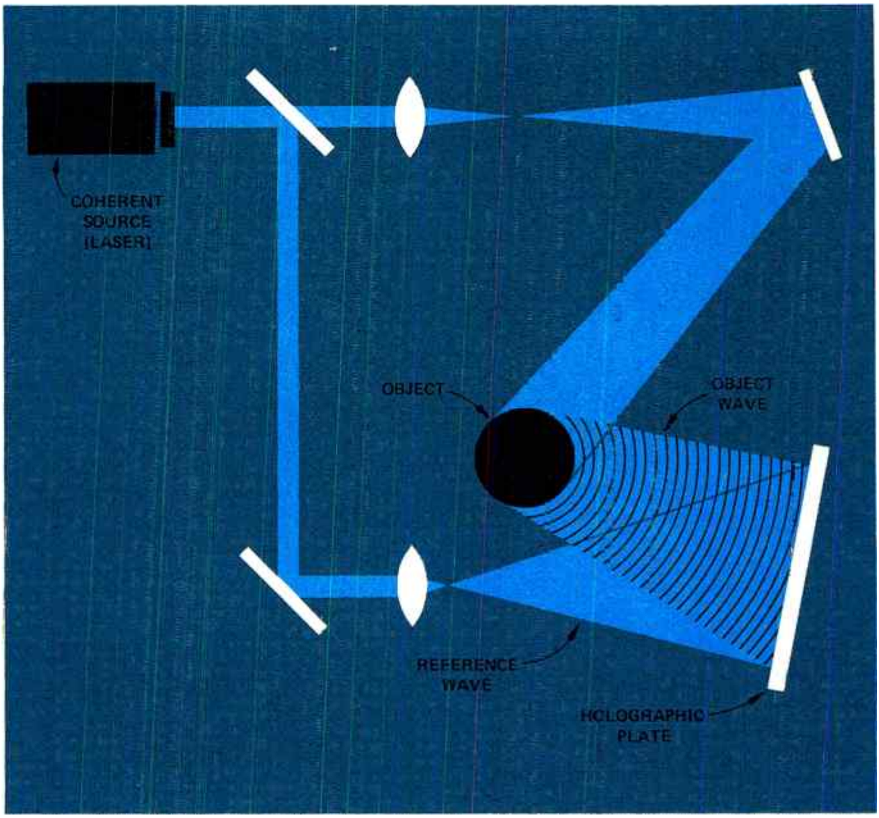

Figure 1. Holographic recording process using laser illumination. The laser beam is split, with the object waves illuminating the object and the reference wave providing a coherent background. The two waves interfere at the holographic plate forming the hologram.

the light is reflected from the hologram to the viewer. A reflection hologram is easier to handle because it may be illuminated in subdued lighting; although, it is not as dramatic as the transmission hologram.

Background

Holography is not a new concept. Dennis Gabor, in 1948, introduced the theory of holography. It was his hope that holography could be used to improve the resolution of electron microscopes. Unfortunately, limited by the intensity of the illumination, the photographic processing, and a disturbing background image, Gabor and the others experimenting with holography did not get the results they desired. The most important of these

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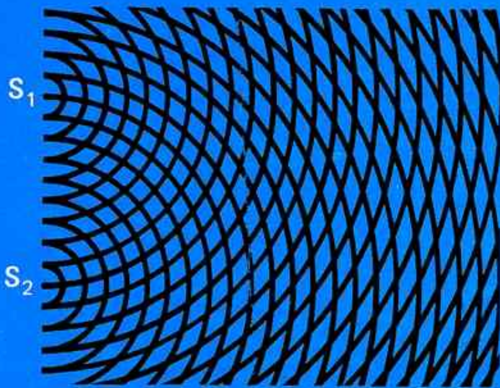

Figure 2. Interference pattern formed from two arbitrary point sources (S_1 and S_2). Place your eye near the left edge and look along the figure. The areas that look white show the cancellation of the waves; between these areas there is reinforcement.

limitations was the illumination intensity.

By 1962, with the development of the laser, intense coherent light became available – over-coming the illumination limitations and eliminating the background image. Laser light also made it possible to record objects which were not easily recorded in Gabor's original system. Objects with dark backgrounds and continuous tones could now be holographically recorded.

Volume Holograms

Gabor's original hologram theory did not use coherent light; therefore, the thickness of the recording emulsion was considered inconsequential and the hologram was viewed as two-dimensional. With the use of coherent laser light, however, the emulsion thickness became an important factor. Specifically, if the emulsion is thicker than the width of the interference fringes (see Figure 3), the object wave and the reference wave will interfere throughout the depth of the emulsion. This produces a volume hologram which is a stack of surface holograms, one atop the other.

If a reflection, volume hologram is made by using three colors of light (blue, green, and red), three holograms will be recorded within the same emulsion. When this hologram is illuminated by white light, each hologram will select the color from the white light to which it responds, and the result will be a three-dimensional color image.

Whole from Part

The entire image from transmission holograms can be reconstructed from a fragment of the original hologram. This is not surprising, since each point on the object is recorded as an interference pattern, or diffraction grating,

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over the entire hologram surface. This grating can be thought of as a Fresnel lens (see Figure 4). Such a lens focuses all the light falling on it at a particular point. A Fresnel lens also has the property that regardless of how many "rings" there are in the lens segment, or whether there is a complete ring, the light will still be focused at the same point. The resolution (clarity) of the point is determined by the number of rings used. Therefore, as a smaller and smaller section of each Fresnel lens or diffraction grating is used, the clarity is diminished, but the point will still be imaged.

For the same reason that a part of the hologram will reconstruct the whole image, the hologram is relatively insensitive to blemishes and dust parti-

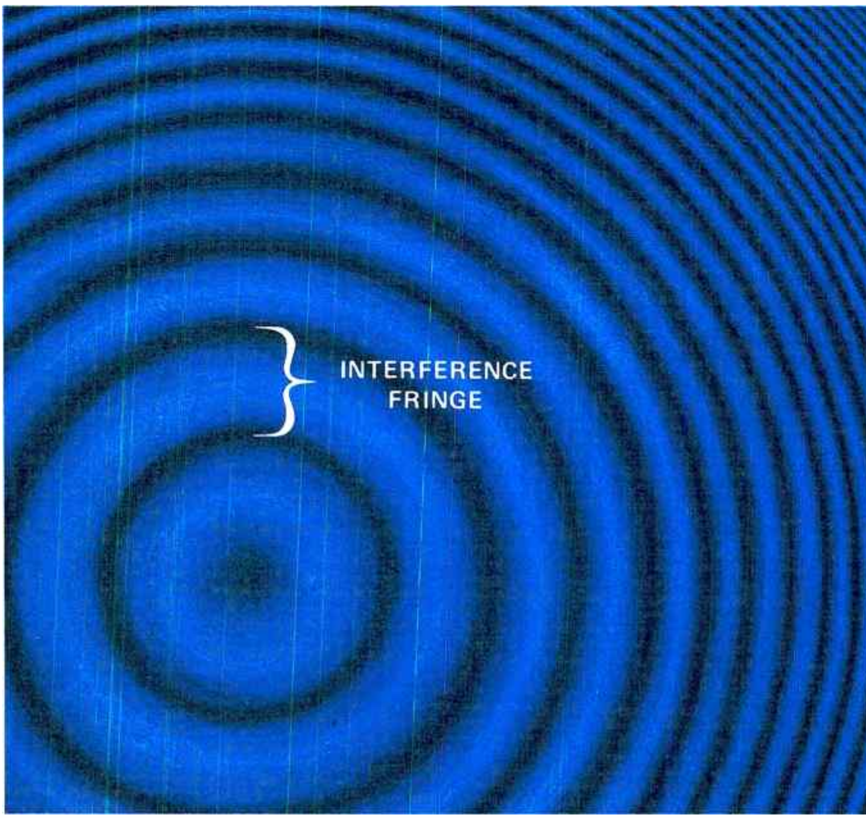

Figure 3. A concentric ring, diffraction grating, for one point on the object, covers the entire holographic plate. The center of the grating need not be on the holographic plate. Such a grating, with variable spacing, focuses the light falling on it at a particular point.

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cles. If a blemish destroys part of a diffraction grating, but not all of it, the light will still be properly imaged. The image will not be destroyed unless the total surface of the hologram has been obliterated.

One Hologram Worth Many Words

The large depth of field of holograms is a great advantage in microscopic investigations. It is particularly valuable for examining moving, microscopic objects in a thick sample. A pulsed laser is used to "freeze" the movement in a sample so it can be recorded on the hologram. When the object is reconstructed and viewed through a microscope, different layers of the sample can be brought into focus – something that cannot be done with a photograph where the movement has been stopped with a strobe light. This principle has been used to analyze the size and distribution of particles in aerosols, liquids, and smog. The old adage, "a picture is worth a thousand words," can be extended – "one hologram is worth a great many pictures."

It was Gabor's hope that holography, being lensless photography, would improve the resolution of electron microscopes. Unfortunately, many of the problems that faced Gabor are still present today; since a magnification hologram has all the distortions observed with conventional lenses.

For holography at non-visible wavelengths, the situation is vastly different. For example, magnification is possible using X-rays for recording and visible light for reconstruction – producing a sharply focused, magnified image. However, the technical problems of X-ray holography are severe, and have prevented its practical realization. Obtaining an X-ray source with sufficient intensity and coherence is a major obstacle.

3-D Imaging

The three-dimensional aspect of holography has received widespread attention. Holography has several advantages related to 3-D imaging. Holographic reconstruction gives an image with high resolution and great depth of field. Parallax, as observed in reconstructed holographic images, allows the viewer to see around objects. Holograms also have some economic advantages such as full color images formed from less expensive black and white emulsions and no need for additional imaging optics.

Holographic three-dimensional imaging also has some disadvantages. The object must remain perfectly still for recording. The object motion can, however, be stopped by using a pulsed-laser for illumination. At the present, it is virtually impossible to take holographic pictures in daylight or under normal illumination because the object to be recorded must be illuminated with only one wavelength of light. Multi-color images are not promising, since these images require long exposures. The size of the object to be recorded is limited by the laser power. The largest hologram that has been made is 18 x 24 inches.

A 3-D holographic television system could be designed today, if available

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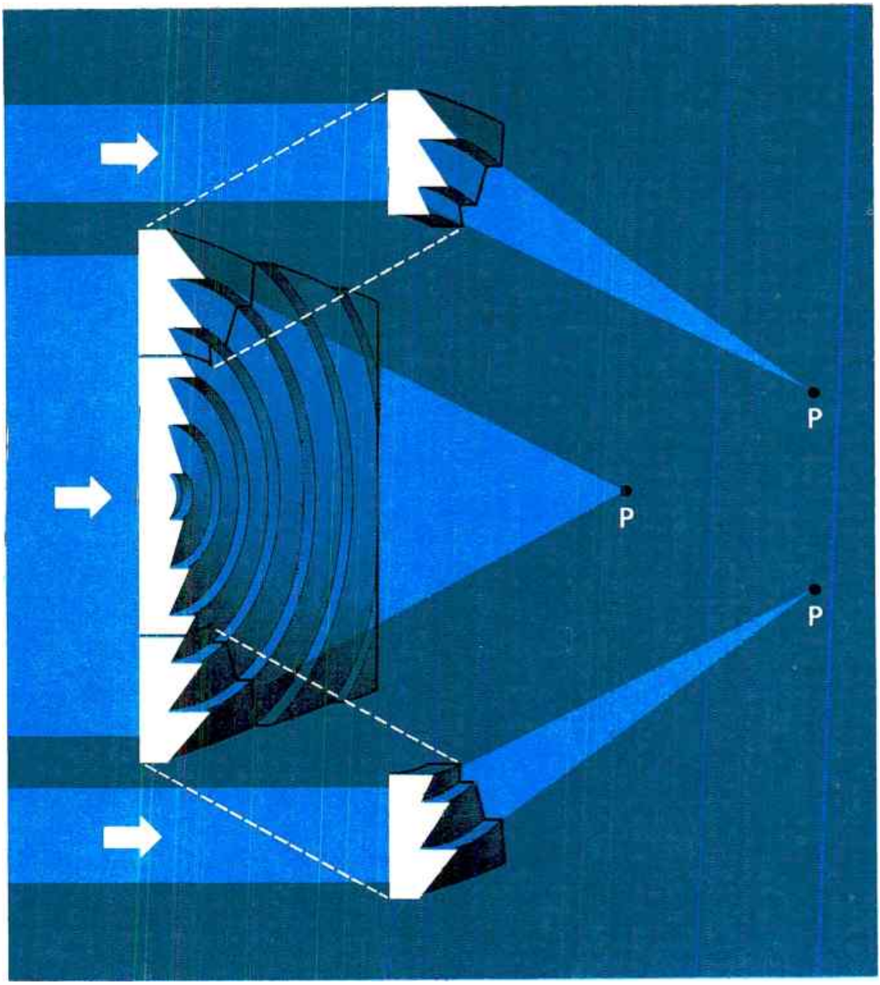

Figure 4. The light falling on a Fresnel lens will focus at a particular point (P) regardless of how large a segment of the lens is used.

components held tighter specifications. For example, a hologram 10 inches square and having 1,000 lines per millimeter has 6 x 10^{10} picture elements, compared with 2.5 x 10^5 for a conventional television picture. If the scan rates of present TV systems were maintained, a 10^5 increase in bandwidth would be necessary – a jump from 6 to 600,000 MHz. The entire radio-frequency spectrum, including the microwave region, would be inadequate to meet this requirement. If a suitable transmission

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method can be found, it may one day be possible to watch holographic 3-D television in the middle of your own living room.

The first attempt at holographic movies involved taking a series of pictures of still objects and then viewing them in rapid succession producing a sensation of motion – the animated cartoon concept. The term "true" is used to describe the newest 3-D movie because it is a motion picture of a moving object. (Figure 5). This reconstructed image is truly three-dimensional and may be viewed without additional lenses or filtérs.

Change Detection

Holography has many properties that make it natural for application to interferometry, a technique used to detect structural changes. For example, a hologram placed in its recording position will display the reconstructed image on top of the actual object. A subsequent slight movement of the object produces interference fringes between the object and image waves.

A hologram can be exposed more than once. The image waves, recorded at different times, can be simultaneously reconstructed and their interference pattern observed (Figure 2). Shock waves, for example, produced by projectiles passing through air or gas density changes can be easily recorded with pulsed-laser, double-exposure holograms.

A new method of holographic interometry (HI) has been introduced which uses a single-exposure, two-wavelength laser pulse in the recording process; rather than the double-exposure, single-wavelength formerly used. This new technique can double sensitivity by proper choice of wavelengths and physical arrangement of components.

The field of nondestructive testing makes extensive use of HI. Holographic nondestructive testing (HNDT) is a method of detecting or measuring the significant properties or performance capabilities of materials, parts, assemblies, equipment, or structures without impairing their serviceability. HNDT is simply HI combined with suitable test-object stressing. Common types of stressing include temperature, pressure, sound, and vibration. HNDT is now a practical design and quality control tool for analyzing sandwich structures, tires, rubber-to-metal bonds, and many other objects. Large areas may be inspected quickly, a variety of flaws can be detected simultaneously, and a choice of several low level stressing methods is available.

Cryptography

A hologram is a coded message that can be decoded by using a coherent illumination source. If, however, the hologram were made with a diffuser such as ground glass placed between the object and the holographic plate, it could only be decoded using the same diffuser. If the same diffuser is placed so that it coincides with its own image, a sharp, clear picture of the original object is reconstructed – as if the diffuser were a clear glass.

The same diffuser must be used in both recording and reconstruction. A section of ground glass, 1 centimeter

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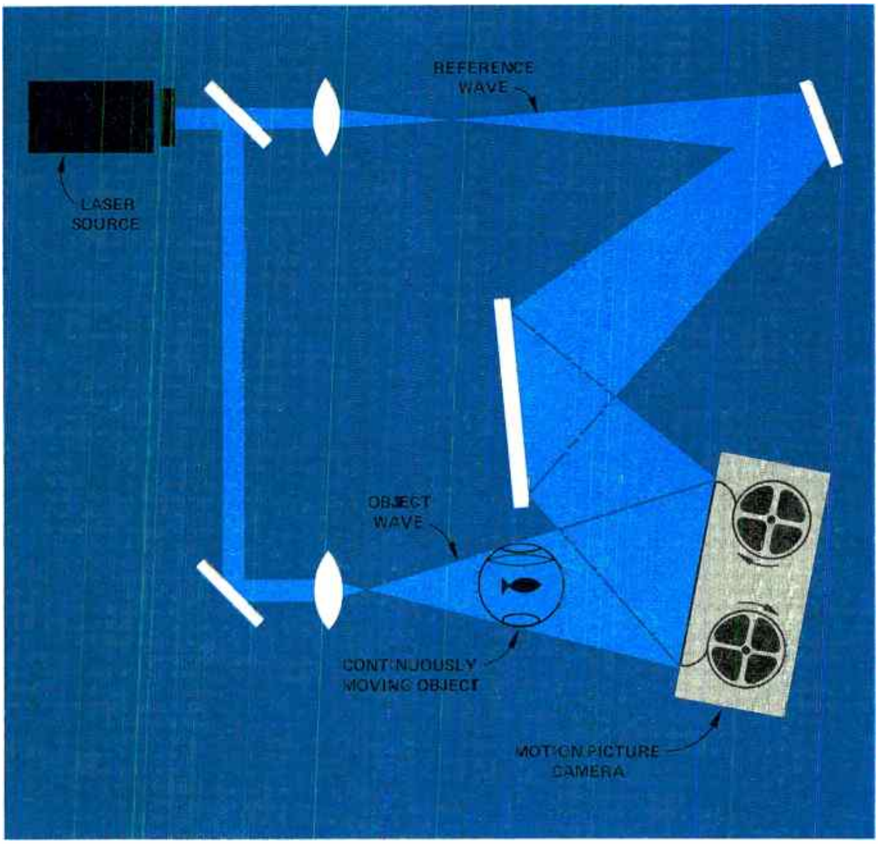

Figure 5. The basic system used to make the first "true" holographic movie.

square, can contain a billion distinct resolution elements, each of which retards the transmitted light. It is not probable that two ground glass samples would be similar enough to allow an image to form. With only one "key" to a cryptographic hologram, the message is considered secure.

Memories Can Forget

Holograms are useful for data storage because many holograms can be superimposed on the same photographic plate. Built-in redundancy is a must in today's computer systems – transmission holograms, with their insensitivity to blemishes and ability to reproduce an entire image from a small fragment, provide the necessary redundancy. Optical memories capable of storing 10^4 bits of data on each page are stored in 1 mm^2 on the hologram. A 10 cm^2 hologram stores 10^4 pages – totaling 10^8 bits per hologram.

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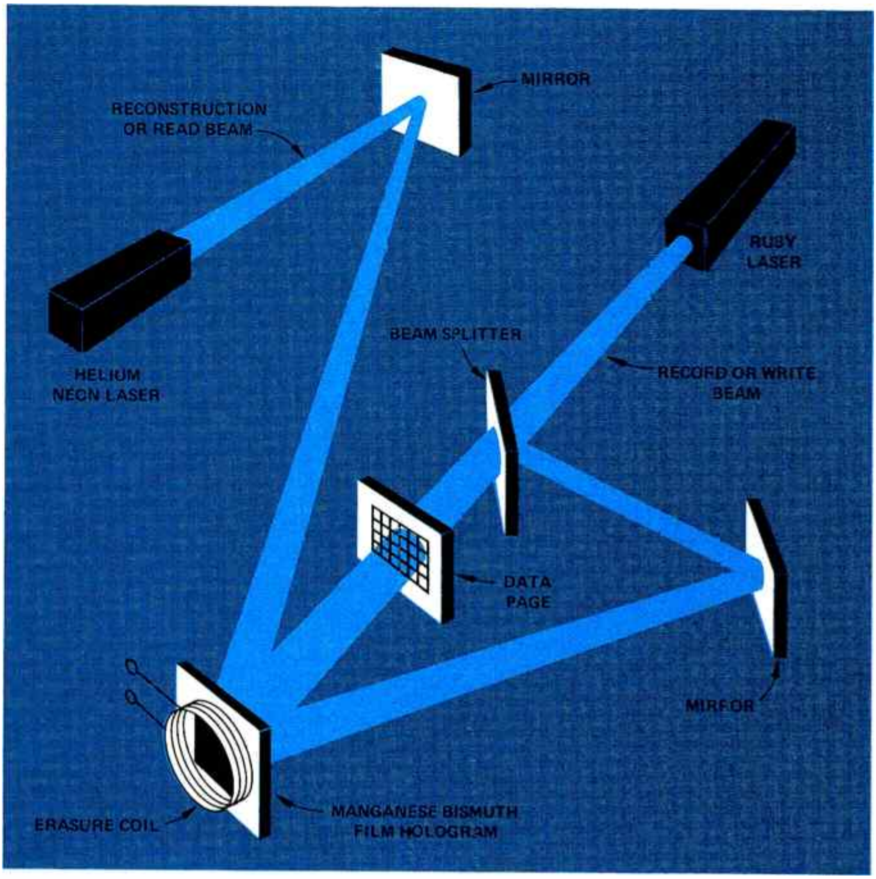

Figure 6. The simplified system for writing, reading, and erasing the magnetic hologram memory.

Until now, optical memories have been confined to the static, read-only type. This means, once made and inserted into the memory, the hologram can be read whenever necessary. This information cannot, however, be changed. Whenever a change is required, the old hologram has to be removed and a new hologram made and inserted into the memory.

A dynamic, read-write memory is now in the laboratory stage. These optical memories are capable of being written in the memory, stored, read at will, and then erased when new information must be entered. Ideally, these can be reused indefinitely.

These new holographic memories are made by depositing a single crystal layer of manganese bismuth (MnBi) on

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a base of mica. A strong magnetic field, applied to this film, causes the magnetic moments of the atoms to line up making it ready for use as a hologram. During the hologram recording process, the magnetic moments of the atoms move out of alignment in accordance with the laser light interference pattern. The recording time for such a hologram is about 10 nanoseconds. The hologram is erased by simply applying a voltage to a nearby coil, creating a strong magnetic field perpendicular to the hologram surface. This magnetic field realigns the magnetic moments of the MnBi crystal (Figure 6). The hologram memory has now forgotten the old information and is ready to record the new data.

Advertising

Reflection holograms have opened the door to hologram use in advertising. Not many people have lasers handy for reconstructing a transmission hologram image, but most people have a white light source, such as a flashlight or high intensity lamp, to illuminate a reflection hologram. Presently, the cost of producing hologram copies is rather high. Holograms, nevertheless, are beginning to appear in the print media.

Advertising holograms seem best suited for inclusion in magazines, although books and newspapers can also carry them. As for direct mail – mailing a hologram is no more difficult than mailing a photograph.

Although many uses have already been made of holograms, there are probably others that have not been explored. Advertising with holograms will provide public exposure to holograms – the more exposure, the more possible applications.

Commercial Applications

Holography is no longer just a laboratory curiosity, but now has applications in the fields of nondestructive testing, microscopic investigation, entertainment, information storage, and advertising. In fact, in the last two years, more than 500 companies in the United States alone, have made economic gains by taking advantage of this extraordinary form of photograhy, which permits the viewer to see around obstacles. Dr. Dennis Gabor, the inventor of holography, has forecast that by 1976 his brainchild will become a billion-dollar industry.

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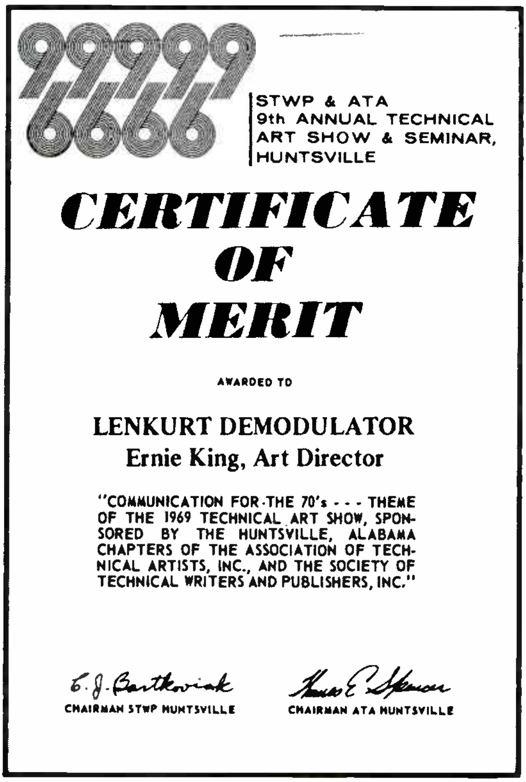

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