HOLOGRAPHY

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Why all this interest? What is behind the great attraction of coherent optics and holography? But first, what is coherent optics? Then, what is holography? Finally, what are we going to do with it?

These and related questions and answers will be discussed at a symposium on holography to be held at the 133rd AAAS annual meeting in Washington, D.C., on 30 December. Speakers will include the following: Dennis Gabor (Imperial College of Science and Technology, London, England); Emmet N. Leith (University of Michigan); Winston E. Kock (NASA Electronics Research Laboratory, Cambridge, Massachusetts); Gary Cochran (Conductron Corporation, Ann Arbor, Michigan); and George W. Stroke (University of Michigan). The symposium is sponsored by AAAS Section M–Engineering.

First, coherent optics—

We have encountered wave coherence in many other forms. It is only recently, with the advent of the laser, that we can approach optical coherence adequate to confirm theoretical expectation.

Sound waves are usually coherent. They follow the laws of interference and diffraction, evidenced by "bad" and "good" locations in auditorium acoustics, and more recently popularized by the "presence" of stereo sound.

Radio and radar waves are usually coherent. They, too, can be expected to sum the contributions of individual radiators or receptors separated in time or space—to synthesize a larger radiator or to derive a real image from a multiplicity of ground reflections. This process has been developed into an exotic detection technique known as "coherent radar."

It was, in fact, from the monumental work in coherent radar that great advances in holography developed. Fifteen years after Professor Gabor invented holography to improve electron microscopy, researchers at the University of Michigan made great advances by applying their well-developed electronic technology with insight into its optical significance.

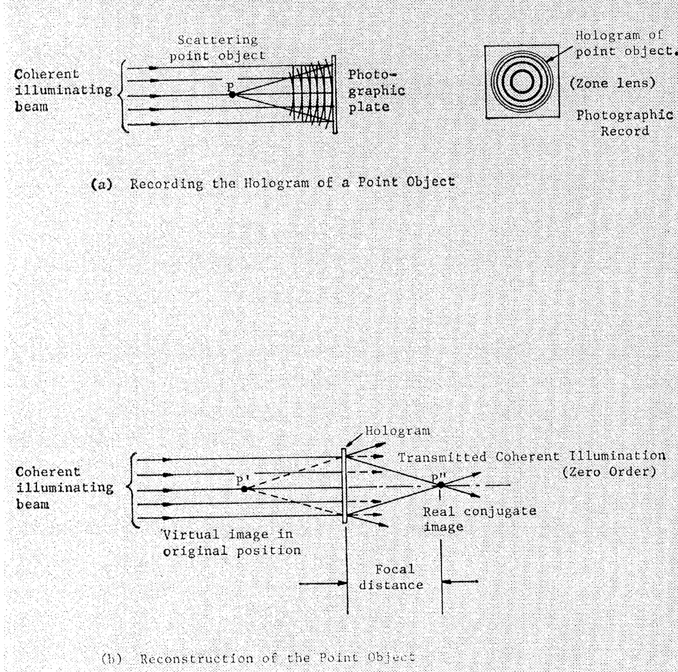
Coherent optics is, therefore, an extension of coherent wave theory into optical frequencies where, until the advent of the laser, coherent optical wavefronts came very dearly. Young's two-slit optical experiment generated two coherent wavefronts by scattering the light by two slits derived from a single almost monochromatic point light source. The radiation from the two slits forms interference patterns which result from the phase additions and subtractions of the two radiating fields, thus demonstrating the wave nature of light. If Young could have synthesized the precise array of many "slits" or "dots" required from a complex object, he would have been able to reconstruct a complex image, not just interference fringes.

Enter holography—This step of synthesizing the "right" array of slits or dots remained latent for many years until photographic emulsions and ingenuity were combined to "freeze" the entire wavefront radiating from an object; the *whole picture*—the *holo gram*. The hologram of a point is a zone lens; the hologram of an array of points, an "object," is a superposition of zone lenses (Fig. 1). When there are an uncountable number of points on the object, there results an uncountable number of zone lenses which, when mixed and superposed, form a jumbled array of noise-like dark and light spots on the film. This is almost the hologram as we know it today. The missing ingredient relates to improved reconstruction fidelity.

If we illuminate a zone lens—a hologram of a point—with a plane wave of coherent light, at least two wave components emanate from the zone plate. First is the residue of the plane wavefront which penetrates the zone plate, unmodified and unscattered. Second is the reconstruction of the point located a "focal distance" from the zone lens. It is the focal point which is desired—the "information." The general illumination is undesired, for it only obliterates contrast between the illuminated point and the background. The general illumination is called the "zero-order" diffraction pattern and the focal point is called the "first-order" diffraction pattern. How to separate the zero order from the first order was the problem.

In coherent radar this is done by effectively adding a reference beam at an angle to the signal beam. The zone lens becomes superposed on top of a diffraction grating, and the first order is diffracted off to a side, out of the path of the undeviated "zero order." When applied to holography, in the form of a reference light beam, not only has the zero-order component been displaced from the first-order information, but the first-order signal is more faithfully reconstructed. This is illustrated in Fig. 2. The amplitude variations of light and dark lines are stored on the hologram and phase variations are represented by variable spacing between the lines.

The entire object is recorded on the hologram plate, derived from all points on the object visible from all points on the hologram. Upon viewing the reconstructed image of the hologram, all points on the object which originally stored their pattern on the plate are reimaged by the plate. The object points will arrange themselves properly in accordance with the angle



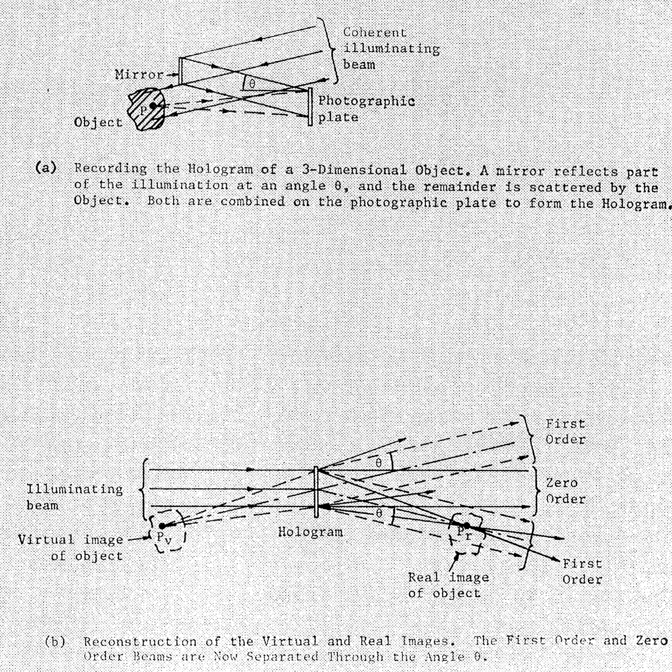


Fig. 1 (left). Basic Gabor method of recording and reconstructing the hologram of a point object. Fig. 2 (right). First improvement in holography by Leith and Upatnieks. Skew illumination is used in recording and direct illumination in reconstruction. [E. N. Leith and J. Upatnieks, *Journal of the Optical Society of America*, December 1963]

of view; a remarkable property which provides complete stereoscopic reproduction of a three-dimensional object.

Now that we have holography, what are we going to do with it?

In the early days of the laser, those who were seeking applications for this remarkable new light source were excited by holography—a wonderful new use for the laser. Now, we ask, "How are we going to use holography?"

This question is more profound than it might appear at first. Holography, with all its truly remarkable properties, is yet to leave the laboratory. In the laboratory or as a research tool, it has yielded startling demonstrations of phenomena involving physical optics.

Holograms of different images may be recorded on the same medium. Holograms of the same image may be reconstructed in different colors with different magnifications, or in the same magnification in multicolor. Since the hologram contains the whole image, all portions of the hologram store the entire scene. Therefore, a piece of a hologram will reconstruct the whole image, suffering only in lost detail over the whole image. The hologram may be encrypted with an almost undecipherable code, and microscopic examination of the hologram record will not even reveal that it has been encrypted.

Some of the unique properties of coherent optical processing may be applied to holography. One of the important mechanisms for object or character recognition is the cross-correlation of an unknown pattern with a known, stored pattern. This operation may be performed by storing holograms of known patterns and optically cross-correlating their images with the unknown patterns. A high correlation "peak" may be expected when the stored image exhibits the same size, shape, and orientation as the unknown, now "identified" as similar to that in the store.

There are signs of commercial adaptation of holography in its true image concept, in which the remarkable stereoscopic properties may be economically portrayed. Holography may be transmitted over television-like systems, but with resolution limited by the electrical "bandwidth" which relates to the number of point samples which are taken of the hologram in an allotted time.

The making of a good hologram requires the stable and precise relative positioning of the laser, the object, and the recording surface (as well as all other elements in the light paths) during the entire recording interval of several to many seconds. We can take advantage of this requirement to sense mechanical instabilities on the order of a fraction of a micron. Thus, extremely small motions and vibrations may be recorded and measured to extremely high accuracy by a method that is not too dissimilar from interferometry.

Holography has been additionally studied for such widely-divergent applications as aerial reconnaissance, simulation and pilot training, data storage, measurement of aerosol particles, and the correction of lens aberrations.

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