

# Early Years of Holography

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The idea of holography came to Dennis Gabor while he was waiting for a tennis court on Easter Day in 1947. Born in Hungary in 1900, Gabor had earned a Ph.D. in electrical engineering from the Technical University of Berlin, then moved to Britain when Hitler came to power. In 1947, he was working at the British Thoms-Houston Company in Rugby and wondering how to improve the resolution of electron microscopes.

Waiting for his tennis match, he wondered how to overcome the imperfections in electron optics that limited resolution. “Why not take a bad electron picture, but one that contains the whole information, and correct it by optical means?” he recalled later. He first thought of illuminating an object with coherent electrons, so interference between electrons scattered from the object and those not deflected would record the phase and intensity of the wavefront. If he recorded the interference pattern and illuminated it with coherent light, he thought he could reconstruct the electron wavefront and generate a high-resolution image.

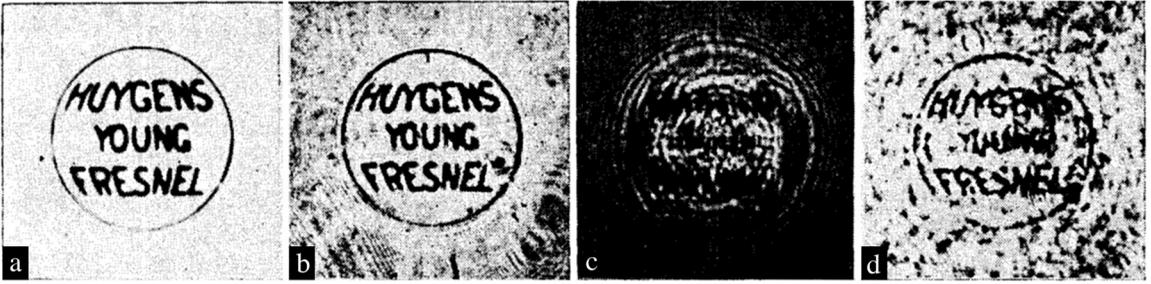
Lacking a way to record electron interference patterns, Gabor tried using light as a model, although he had not worked with optics before. The best available coherent source at the time was a high-pressure mercury lamp, but its coherence length was only 0.1 mm, and filtering it through a pinhole left only enough light to make 1-cm holograms of 1-mm transparencies. Nonetheless, he made recognizable holographic images in 1948 (Fig. 1), a dozen years before Theodore Maiman made the first laser.

Gabor’s report in *Nature* in 1948 [1] raised the possibility of three-dimensional (3D) imaging, generating considerable attention, and helped him land a professorship at Imperial College in London; but progress was slow, his design generated twin overlapping images, and the short coherence lengths of available light sources limited imaging to small transparencies. By the mid-1950s, Gabor and most others had largely abandoned holography.

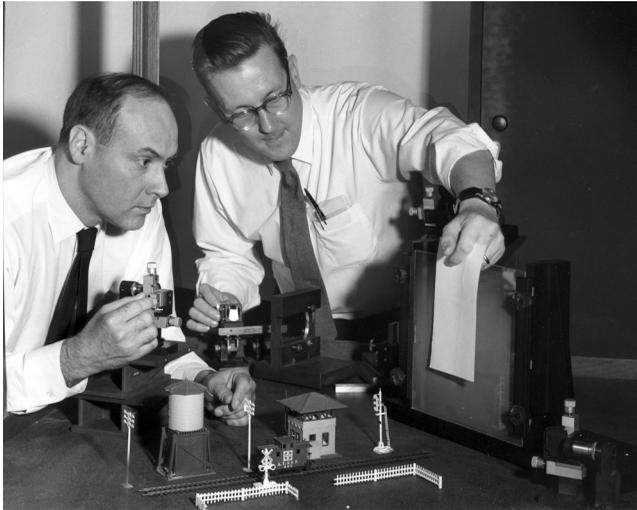
The revival of holography grew from a completely independent direction: classified military research on synthetic aperture radar launched in 1953 at the University of Michigan’s Willow Run Laboratory. The following year, a young engineer named Emmett Leith who had studied optics at Wayne State University began developing an optical system to perform Fourier transforms of radar data collected by flying over the target terrain. He and Wendell Blikken started with incoherent optics, but Leith later said many of their problems “just melted away” when they considered coherent light in 1955. They did not need much coherence and they eventually found that focusing all the light from a point source onto another point would suffice for radar processing.

In September 1955, Leith realized that the light waves diffracted from the data record were replicas of the original radar signals converted to optical wavelengths. That led him to a theory that mirrored Gabor’s wavefront-reconstruction holography but shrank the radio waves to optical wavelengths rather than stretching electron waves to optical lengths. He knew nothing about other research in holography until a year later, when he discovered a paper by Paul Kirkpatrick and Hussein M. A. El-Sum in the *Journal of The Optical Society of America* (JOSA) [2].

Holography intrigued Leith, but the radar project kept him too busy to experiment until 1960, when Willow Run hired Juris Upatnieks as a research assistant in the optics group. Born in Latvia in 1936, Upatnieks fled with his family when Soviet troops occupied Latvia in 1944. They spent years as refugees in Germany before moving to the U.S. in 1951. He had a fresh degree in electrical engineering from the University of Akron (Ohio) but lacked a security clearance, so he could not work on the radar project.



▲ Fig. 1. Dennis Gabor's first hologram. (Reprinted by permission from Macmillan Publishers Ltd.: *Nature* © 1948.)



▲ Fig. 2. Emmett Leith and Juris Upatnieks in 1965. (Courtesy of Juris Upatnieks.)

Leith put Upatnieks to work making Gabor-style holograms while they waited for his clearance. Despite lacking optics experience, Upatnieks succeeded. The reconstructed images were fascinating but had the same twin-image problem as Gabor's.

However, Leith's theory of holography offered a crucial insight because it described a signal modulating a carrier wave, which produces sidebands at the sum and difference frequencies, above and below the carrier frequency. Leith realized that Gabor's twin images were the two sidebands. Eliminating one of them should leave a single clear image. (Figure 2 shows them with their holographic setup.)

Leith suggested separating the object and reference beams so that they reached

the photographic plate at different angles. However, that proved hard until they used a diffraction grating to split light from a mercury-vapor lamp into different diffraction orders, and using one as the reference beam and the other as the object beam. That yielded the first off-axis holograms, and Upatnieks's experiments confirmed Leith's theory. Leith described the results at OSA's October 1961 meeting in Los Angeles and submitted a paper to *JOSA* [3].

By then, the military had called Upatnieks to fulfill his obligations from ROTC in college. When he returned to Willow Run in November 1962, he started a new round of holography experiments with a mercury lamp, but an early commercial helium-neon laser was sitting temptingly in a nearby laboratory where Anthony VanderLugt was using it in image-recognition experiments. Inevitably, as Upatnieks says, "We kind of talked him into letting us borrow his beam. We put a mirror in his room, and bounced the beam off to our setup."

Based on a standard optical bench, their new setup expanded the laser beam and split it by passing it through a wedge prism. Recording good holograms required extra-flat glass plates that Kodak had developed for spectroscopy. Exposure was very slow, so the laser's higher intensity was a big advantage. Leith and Upatnieks reported a dramatic improvement in hologram quality at the March 1963 OSA meeting in Jacksonville and in a paper in the December 1963 issue of *JOSA* [4]. The holographic reconstruction of a 1.5-cm slide in the published version is hard to tell from the original. Holographic reconstructions of slides of a child in an outdoor scene and an adult portrait are speckled but clear.

Lasers brought speckle to holography, but their higher power and longer coherence length made experiments easier. More important in the long run, laser coherence allowed fully 3D holography of

opaque objects. Leith and Upatnieks spent a couple of days trying 3D holography in July 1963 but failed and turned to other work.

They returned to 3D holography after the JOSA paper came out and reporters asked Leith what might come next. “He offhand mentioned that 3D objects could be recorded and they would be three dimensional, and no one believed it,” Upatnieks recalled. “Since Emmett said it would be done, we had to show it,” and they went back to 3D holography.

They faced tough technical problems such as isolating their holographic setup from wavelength-scale vibrations. Moving to a massive granite optical bench improved image clarity, but the 3D images did not seem dramatic until Leith and Upatnieks started using objects a few inches across, large enough for the eye to see as three dimensional. Holograms recorded on 4- by 5-in. plates were “incredible, just totally incredible, the one thing that excited us most,” Leith recalled.

Their first image was a pile of loose objects they obtained from the laboratory; it looked like a pile of junk, interesting only because it was a hologram. As they refined their technique, they found an iconic object that made a striking hologram—an HO-gauge toy train engine that they filled with epoxy and glued to the tracks to stabilize it (Fig. 3). They recorded two holograms on the same photographic plate mounted at different angles, then reconstructed the two images separately without crosstalk by illuminating the plate at the proper angles.

Visitors streamed through the lab to see the holograms, but the floodgates opened in April at OSA’s 1964 spring meeting. Upatnieks presented a 15-minute paper on Friday afternoon, the last day of the meeting, titled “Lensless, three-dimensional photography by wavefront reconstruction,” but the talk could not match a demonstration. Attendees lined up in the hall to see a He-Ne laser illuminate a hologram in a hotel suite rented by Spectra-Physics. They stood and studied the holographic toy train floating in space, then looked around to find the hidden projector that was fooling them. Leith called that “the high point in the dissemination of holography” [5].

The optics world was enchanted by holography, and specialists hurried home to try to make their own holograms. Most failed on their first attempts and called Leith and Upatnieks for help. “Those calls kept us quite busy for a while, but that was how holography took off,” Leith recalled.

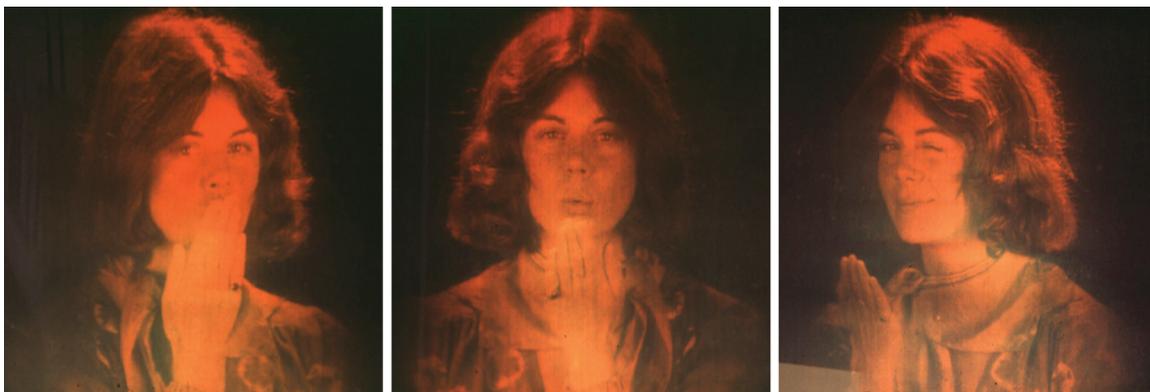
Enthusiasm spread fast, as it had for the laser. It was a boom time for technology, and, like the ruby laser, holography could be duplicated in a well-equipped optics lab. Could holography be the problem that the laser was searching to solve?

It took time to assimilate the concept. The first issue of *Laser Focus* in January 1965 called it “3-D lasography” [6]. Others called it lensless photography or wavefront reconstruction. *Scientific American* called its June 1965 article “Photography by laser” and showed two holographic chess pieces on the cover [7]. Leith and Upatnieks used Gabor’s term, hologram. By any name, holography had potential. Its images shimmering in mid-air looked so real that people reached out to touch them.

Among the burst of innovations in the holographic boom was the rediscovery of reflection holography invented by Yuri Denisjuk at the Vavilov State Optical Institute in the Soviet Union. Instead of directing the object and reference beams onto the same side of the photographic plate, Denisjuk illuminated the object *through* the plate, with the reflected object light interfering with the reference beam in the plane of the plate. He demonstrated the technique with mercury lamps; but his experiments ended in 1961, and his two papers published in Russian in 1962 were ignored until three American labs stumbled upon the effect independently in 1965. Importantly, Denisjuk reflection holograms can be viewed in white light.



▲ Fig. 3. Iconic photo of holographic toy train. (Courtesy of Juris Upatnieks.)



▲ Fig. 4. “Mini Kiss II”: Pam Brazier in holographic stereogram. (Courtesy of MIT Museum. Mini Kiss II, Lloyd G. Cross, 1975. <http://web.museum.mit.edu/imagerequest.php?imageidnumberMOH-1978.52.01> [all three views].)

Another major imaging advance came was the invention of “rainbow” holograms by Steve Benton at Polaroid in 1969. Seeking to make brighter images, he produced reflection holograms that displayed depth only in the horizontal plane, the only one in which our eyes see parallax. This allows the hologram to diffract the whole visible spectrum, spread across a range of angles to produce a rainbow of colors. Easily visible under normal lighting, such holograms can be embossed onto metal films and they have become the most widely used holograms.

In the early 1970s in San Francisco, Lloyd Cross developed a variation on rainbow holography that offered an illusion of motion. He produced the holograms in a two-stage process. First, he took conventional photographic transparencies as he moved around a person or object, and then he recorded rainbow holograms of the series of transparencies as successive narrow stripes on film. Finally, the film was mounted in a 120-deg arc or a 360-deg cylinder.

The viewer’s eyes saw different frames, giving the parallax that the brain interprets as depth. If the model moved between frames, a viewer saw the movement while moving around the curved hologram. Cross formed a company called Multiplex to make the holograms; the best known one shows Pam Brazier blowing a kiss to the viewer (Fig. 4).

In October 1971, when the holographic imaging boom was in full flower, Dennis Gabor received the Nobel Prize for “his invention and development of the holographic method.” Many in the optics community felt that Leith and Upatnieks should have shared the prize for reviving holography with lasers and their solution of the twin image problem.

In his book *Holographic Visions* [8], science historian Sean Johnston blames George W. Stroke, who in 1963 started a holography program on the Michigan campus that came to compete with Leith’s work at Willow Run. Stroke eventually left Michigan carrying a grudge and claiming that his work was more important. This was long a common view in the optics community.

However, in her dissertation on the history of holography written at Cambridge University [9], holographer Susan Gamble argues that the problem was that Leith and Upatnieks worked at a military lab. Michigan students had protested Willow Run’s military projects, and in 1971 opposition to the Vietnam War was widespread in Europe. The Nobel committee may well have decided that awarding a Nobel Prize for military work would send the world the wrong message.

If some optical Rip Van Winkle from 1970 woke up today after his long nap, he might ask, “Whatever happened to holography?” Holographic imaging never came to movies or television, and the “holographic telepresence” of convention speakers is based on the old “Pepper’s Ghost” illusion rather than real holograms. Yet holographic displays have found some specialized niches. Furthermore, holograms are used in industry in many ways that go unrecognized, such as holographic optics, and security imprints on packaging and some currencies. We may never watch wide-screen movies in glorious holo-vision, but who would have expected us to be carrying holograms in our pockets on credit cards?

Note: This chapter is adapted from [10].

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