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HOW TO MAKE
HOLOGRAMS

BY DON McNAIR

To Sharon McCormack—
Thank you for your help!
Don McNair

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Foreword

Holography has many faces, and different people see it differently. To some it is a laboratory technique for nondestructive testing, such as the examination of metal fatigue or welds, or an invaluable way of visualizing fluid flow. To others, it is a way of making new classes of optical elements, either diffraction gratings or lenses. Some use it in optical processing applications, such as pattern recognition. Still others make holograms so that they can marvel at the incredibly realistic images that result. This latter group is a large and varied one. It includes artists, who find in holography a new medium for artistic endeavor, and amateurs who simply want to make their own holograms and learn first-hand about this astonishing photographic technique. Also in this group are scientists and engineers who, seeking a brief respite from their technical projects in holography, make holograms simply for fun. Above all, holography is fun.

Holography is also a great unifier of diverse people. It brings together in a working relationship many persons who would not normally interact at all. The scientist who develops a method for brighter or clearer holograms finds himself drawn into relations with artists who are diligently trying to improve their own technique; the artist realizes that holographic art can bloom only in direct proportion to the technical excellence of the hologram.

I have always felt that, whatever the commercial or engineering applications for holography, its true essence must always be the display aspect. It is this aspect, almost entirely, that propelled holography into the widely recognized position it occupies today. The one single event in this propulsion process was the holographic display given at the April 1963 meeting of the Optical Society of America in Washington, D.C. There, hundreds of optical scientists stood in line to get their first glimpse of holographic photography. They were thoroughly fascinated, and even though they were scientists, many asked the same questions that newcomers to holography ask today: where is the image? (It's not at all obvious that it comes from the glass plate.) Where is the object hidden? (The presumption is that it's tucked away in some nearby place, and the whole thing is done with mirrors that

cleverly project an image in some obscure way.)

These scientists, upon returning to their laboratories, began making their own holograms. Despite the frustrations that some experienced, they had fun.

The entry of Juris Upatnieks and myself into holography (optical holography, that is) was strictly as a fun project, with no applications whatever in mind. We had earlier, since 1955, applied the ideas of holography to the production of high quality radar imaging, and our work had been extraordinarily successful. Then, in 1960, we turned our attention to the process of holography as a thing in itself. We were familiar with the papers of Dennis Gabor, and we decided to duplicate his experiments. Gabor had used simple transparencies containing lettering. His reference beam was just the straight-through beam—the portion that was not obstructed or scattered by the lettering. As expected, the process worked, although the imagery was of poor quality. Nevertheless, we found the process to be fascinating and even somewhat eerie. Here was an image formed by rays of light. One would normally expect that, if these rays were traced upstream, they would lead to an object, as with ordinary imaging processes. But here, the rays ended abruptly at the hologram, and there was no object to be found. Here was a strange optical system that formed images seemingly without any need for an object. To some of our colleagues who viewed the system, it seemed more like witchcraft than science. Thus holography, even in its infancy, held a peculiar fascination. I presume that Gabor and his colleagues, who witnessed holographic imagery for the very first time, must have found this result quite awesome.

We next embarked on a research program, again strictly for fun. It seemed a shame that such a fantastic process should produce only rather poor images. We speculated on ways that the process might be improved so as to yield good images. One problem with the process was that it made two images, in two different planes, and one always had to view one image against a defocused second image.

After some thinking, we hit upon the method of introducing a reference beam separate from the object, one that went around the object and impinged on the recording film at some oblique angle. A lot of effort was required to perfect it, but it yielded a new kind of hologram, characterized by a fine-line structure; it was really very much like a diffraction grating. When illuminated, it produced various diffracted orders, just as a diffraction grating does. In the zero order it would, like the Gabor in-line hologram, produce the usual inseparable twin images. Another component of light emerged from this hologram at an angle, however, and this was one of the first order diffracted beams. When it separated from the center beam, it was found to contain only one of the two images. The other had completely vanished. In fact, the other image was to be found in the other first diffracted order, on the other side of the center beam.

We were elated at this success, which resulted in imagery of higher quality than the holographic process had ever before produced. This success, like Gabor's original work, had been achieved with the quasi-coherent light of the conventional mercury arc source. The laser, which later was to play a crucial role in holography, was only then being invented. It would still be more than a year before it became generally available.

It is sometimes erroneously assumed that off-axis holography became possible only with the laser. The fact is that the requirements on source coherence are not intrinsically any different than for Gabor's in-line method. For simple objects, such as photographic transparencies, these requirements are rather slight, so that the mercury arc source really gave many times better coherence that was needed.

We continued developing the holographic process, and when the laser became available to us in 1962, we explored ways of using its enormous brightness and coherence. The principal result was the use of actual, reflecting, three-dimensional objects instead of mere transparencies. For such objects, the coherence requirements are so great that the laser is a necessity. Now holography became truly exciting and could be appreciated by all, rather than by an esoteric group of scientists. The three-

dimensional imagery that resulted, complete with parallax, was radically unlike any images heretofore seen. The holographic image seemed more like a recreation of reality than just a mere picture. It was these holograms that we took to the Optical Society Meeting, and that started holography on its way to the big time. It had all been done purely for fun—an unfunded project carried out in a corner of the laboratory.

About the same time we were enjoying ourselves in holography, Yu. N. Denisyuk in the Soviet Union was inventing reflection holography, which permitted holograms to be viewed with white light. Today his system is highly perfected and produces some remarkable images.

Toward the close of the holographically active 1960s, Stephen Benton invented the rainbow hologram, which also allows white light viewing. Shortly thereafter, Lloyd Cross gave us white light viewable multiplex holograms. These three white light hologram types have considerably expanded the horizon for display holography, first, because one no longer needs an expensive and not usually available source for viewing holograms, and second, because holographic images look better under white light illumination.

No one ever tires of looking at new holograms, and whenever holographers get together they derive unending enjoyment from looking at each other's latest holograms. New holographers are afflicted from the start, and old holographers never tire of this pastime. Holography thusly remains as fresh today as it was in those exciting years of basic holographic development.

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