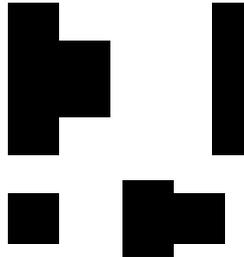


# Computer Generated Hologram CGH

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## Abstract

This document is an introduction to the design and fabrication of computer generated hologram (CGH) as I understood them back in 1997. At that time, I was visiting Professor Toyohiko Yatagai<sup>1</sup> in Japan. I also included in this document a short description of the application 'DoCGH' that I wrote to generate simple hologram. This work was supported by a grant of the Swiss Academy of Engineering Sciences (SATW). This document is available on line 'as is'. No responsibilities can be taken. The reader must assume the entire risk, if any, of using the information provided.

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# 1 Introduction

Holography [1] is a technique involving the recording and reconstruction of waves based on the pioneering work from D. Gabor<sup>2</sup>. The coded recording of a wave is called a hologram. In conventional holography, a wave front diffracted by the object propagates to the hologram plane, where it interferes with a reference beam (Figure 1). The resulting intensity pattern is recorded on photographic film or plate to form the hologram. To decode the information from the hologram and reconstruct the object wave, the reference wave is again used to illuminate the hologram [2].

Computer generated holography is a more flexible process. First, a physical object is not needed. It is sufficient to have a mathematical description of the object. Second, different encoding techniques that enable physical recording of the complex wave front, can be used.

Freedoms on the object description and encoding techniques directly yield to some of the CGH applications : spatial filtering (optical data processing and optical computing), optical shop testing (generation of reference wave fronts for optical testing) and three dimensional display [3].

To fabricate CGHs, an enlarged sample of the computed hologram is plotted. Then a photographic reduction forms the hologram with the desired final size. In recent years, CGHs have been fabricated by direct write with a laser beam system or electron beam lithography system to benefit of a resolution impossible to reach with photographic techniques.

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<sup>2</sup>Dr. Dennis Gabor (1900–1979) was a Hungarian scientist who recieved in 1971 the Nobel prize in physics for his investigation and development of holography.

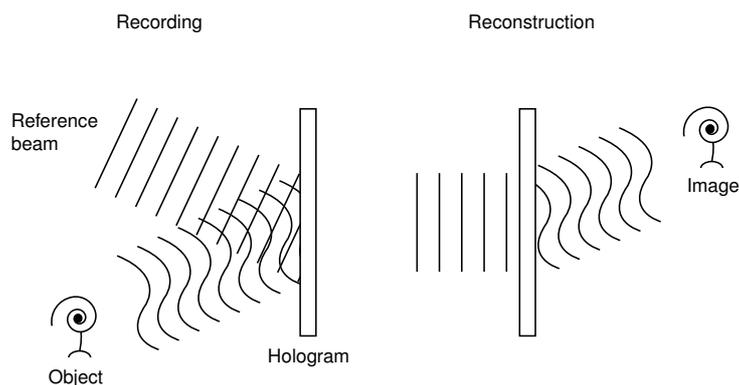


Figure 1: Principle of holographic recording and reconstruction.

## 2 Creating a CGH, a step by step tutorial

### 2.1 Object

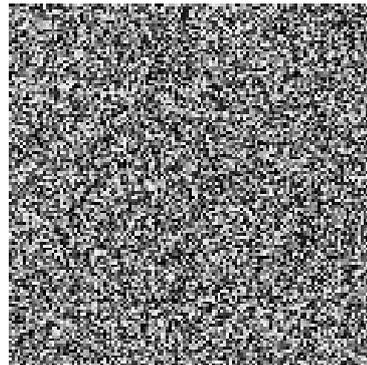
No real object is needed. It's possible to generate the wave front of an imaginary object. You only need a mathematical definition of what you want. Let's write 'SATW'.

### 2.2 Required definitions

The application requires a 'complex' definition of your object. The amplitude and phase of the diffracted wave from the imaginary object are defined by two arrays of byte values. In general a real definition of the object is given and random phase is generated. This is a simple means to spread the information across the hologram area to obtain a better quality [3].



Amplitude



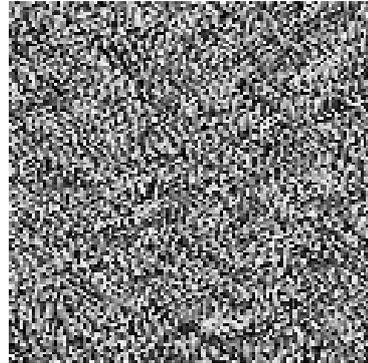
Phase

### 2.3 Transfer from object to hologram plane

Once the wave object is defined one have to calculate its propagation to the hologram plane. There is different types of hologram. The simplest type is called Fraunhofer and is valid at great distance or in the focal plane of a lens [2]. For this type of hologram, the transfer calculation is simply a Fourier transform of the object.



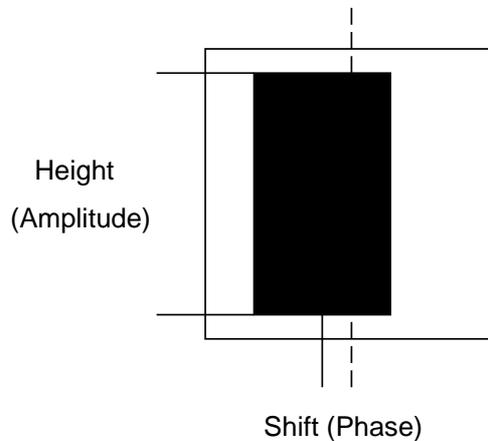
Amplitude



Phase

## 2.4 Encoding scheme

There is a few simple techniques to encode the complex wave front such that it can be recorded on physical media [3]. Brown and Lohmann<sup>3</sup> have described the first and one of the best schemes [4]. It's a binary (black or white) hologram constituted of rectangles written in cells with their height coding the amplitude and their shift relative to the cell pattern the phase.

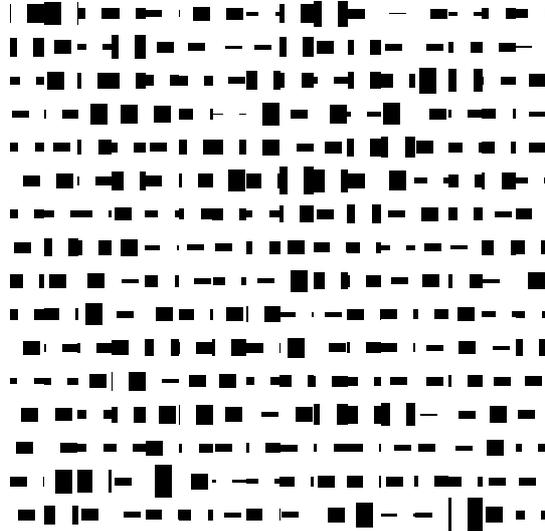


## 2.5 Fabrication

The generated hologram is now printed on a laser printer and then photoreduced on a high contrast black and white negative as Fuji minicopy. Once developed, the negative is the hologram.

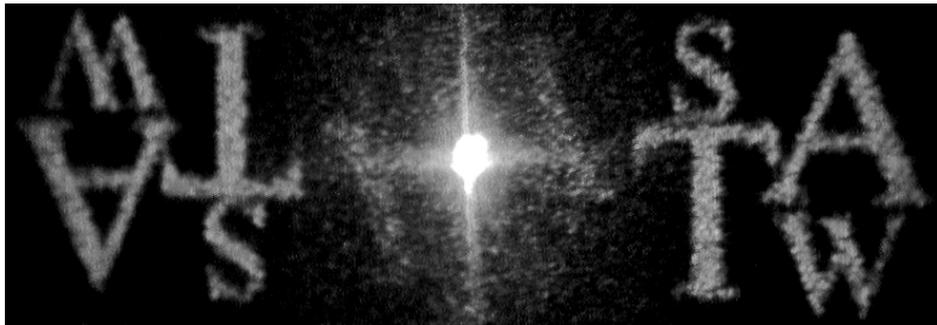
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<sup>3</sup>Brown was working for the IBM research laboratory of San Jose, California and Lohmann address was at the Department of Applied Electrophysics, University of California (San Diego).



## 2.6 Image reconstruction

To reconstruct the object wave, illuminate the whole hologram surface uniformly with a laser beam, and observe it on a white board at a large distance or at the focal length plane of a lens. If you have a laser pointer and an old binocular or telescope, they can be used to illuminate the CGH with an enlarged beam.



## 3 DoCGH application

Here his a short description of the application's toolbar:

**Size**            The number of pixels that define the object.

<b>1 Amp</b>	Set the amplitude of the object to the constant 1.
<b>0 Pha</b>	Set the phase of the object to the constant 0.
<b>R Pha</b>	Set the phase of the object to random data.
<b>OA</b>	Set the amplitude of the object based on a text or bitmap file.
<b>OP</b>	Set the phase of the object based on a text or bitmap file.
<b>SA</b>	Save the amplitude of the object in a text or bitmap file.
<b>SP</b>	Save the phase of the object in a text or bitmap file.
<b>FFT</b>	Perform a fast Fourier transform from the object amplitude and phase. If you prefer, calculate the wavefront at the hologram plane.
<b>iFFT</b>	Perform an inverse fast Fourier transform.
<b>Lohmann</b>	Encode the wave using Lohmann's technique.
<b>Lee</b>	Encode the wave using Lee's technique.
<b>Paper</b>	Select the size of the paper for the generated EPS files.
<b>1 EPS</b>	Generate one EPS file. The hologram is printed on 1 page.
<b>2x2 EPS</b>	Generate 4 EPS files. The hologram is printed on 4 pages.
<b>4x4 EPS</b>	Generate 16 EPS files. The hologram is printed on 16 pages.
<b>Ebeam</b>	Generate the needed files to drive the Elionix 3300 Electron beam machine.
<b>Exit</b>	Close the application.

## References

- [1] D. Gabor. A new microscopic principle. *Nature*, 161(4098):777–778, 1948.
- [2] J.W. Goodman. *Introduction to Fourier optics*. McGraw-Hill, Inc., New York, 1968.
- [3] W-H. Lee. *Computer Generated Holograms: Techniques and applications*.
- [4] B. R. Brown and A. W. Lohmann. Computer-generated binary holograms. *IBM J. Res. Develop.*, 3:160–168, 1968.