6 December 1965

Tests of Minicard FE-5142 film extended to red-sensitive range.

This film was tested to determine its resolution capability and its suitability for recording holograms. By recording the interference pattern of one collimated beam and one spherical wavefront, special frequencies up to 2600 lines/mm were recorded. It seems that higher special frequencies could be recorded. The exposure times were about 1/10 sec. and the film exhibited characteristics of being extremely high contrast.

Several holograms were made with an angle of about 30° between the reference and signal beams. Reconstructions were obtained, but the intensity of the image was low and the scattered light level was high. Holograms were made under identical conditions on 649F emulsion on glass plates and film. The images on glass plates were very clear and sharp and exposure time of 3 minutes was required. Images on the film were of lower intensity, in spots did not reconstruct due to vibration of film, and required exposures times of 10 min., compared to 1 min. for the minicard film. The minicard film behaved as a low contrast film at these exposure levels. The 649F emulsions were developed for 6 min. in Kodak P-19 developer, the minicard for 4 min. in the same developer. The reciprocity law apparently does not hold for the minicard film at low light levels. The films were sandwiched between two glass plates during the exposure, but apparently some vibration was present.

Juris Uspatnieks, 6 Dec. 1965
6 December 1965

Reasons for some of the imperfections in enlargements of microscope slides using hologram tech.

The enlargements of microscope slides made in summer of 1964, and shown on page 50 of the previous notebook show several defects. Two of these are the superposition of a grating-like structure, the other is a darker background brightness variation. The same original fly's wing was examined in laser light under both high and low magnification. Under high magnification, the grating-like structure was clearly visible. Apparently it is caused by reflection from one or two of the four surfaces (the fly's wing was mounted between two glass plates). Under lower magnification, the graver structure was also visible. This might also be caused by interference from multiple reflections, or it might be caused by highly irregular glass surface. Anyhow, these two defects are caused by the manner of mounting the specimen and not by the hologram process itself.

Jānis Upiņš, 6 December 1965
8 December 1965

Experimental verification of the cause of forward images in holograms made with reference beam from the back.

Holograms made with the reference beam from the other side of the photographic plate exhibited some unexpected properties. These were that images also reconstruct if the hologram is illuminated in the ordinary manner, with light illuminating the plate from one side and the observer viewing it from the other. Two such images are visible, one on either side of the reference beam. An explanation proposed by lith and others suggested that internal reflections of the signal and reference beams cause these other two images.

To verify this idea, a hologram was made with this optical system:

Juris Uspatnieks, 8 December 1965
3 December 1965

The intensity of reference beam was $3 \times 10^{-5}$ and of signal beam $18 \times 10^{-7}$ measured with 5.7 M light water. Exposure time was 70 sec. and the plate was slightly overexposed. A 90° prism was placed on the glass side of the plate with xylene liquid between the surfaces to eliminate surface reflections.

If internal reflection at the emulsion side of the reference beam is cause of any image then the source should appear to be near the object and reconstruction should be possible:

![Diagram showing apparent position of reference point source and object](image)

In reconstruction, the image appeared to come from the same location where the prism was in place, thus verifying that this image indeed comes from the reflected reference beam.

The other image could come from internal reflection of the signal beam. The following diagrams apply in this case:

![Diagram showing reconstructed image with prism in place](image)

Juris Upatnickis, 3 December 1965
8 December 1965

The reconstruction showed the images to be located as shown in the above diagram. The apparent location of images in the left figure could be observed by placing a transparent glass plate with the prism in some place where the hologram was made.

Observations of the reconstructed hologram are in good agreement with the above predicted location of images.

Juris Upatnieks, 8 December 1965
24 December 1965

Expected quality of reconstruction from plane-wave
signal laser holograms.

Consider an optical system with the object consisting
of a transparency, the encoding plate of purely
plane variations, and the encoded signal being
recorded on a hologram.

\[ s(x,y) = a(x,y) e^{i \theta(x,y)} \]
\[ g(x,y) = e^{i \chi(x,y)} \]

\[ F(s) = S(\omega_x, \omega_y) \]
\[ G(g) = G(\omega_x, \omega_y) \]

(Note: spectrum of \( G \) is actually amplitude-varying)

\[ G = \begin{cases} 
G' & \omega \leq \omega \leq \omega_1 \\
G'' & \text{elsewhere}
\end{cases} \]

Let \( (s * G)' = S' * G' \)

where \( S' \) is actual portion
of \( S \) recorded on a hologram.

Juris Upatnieks, 24 December 1965
The hologram records a transform of the product of $s$ and $g$; however, we can talk about recording portions of $s$ and $g$ too. Let us consider the recording and reconstruction process in the Fourier transform plane.

$$f(sg) = s \ast g$$

Assume hologram records spectrum between frequencies $a_2$ and $a_1$ only. Then the hologram records $(s \ast g)'$ only, and the reconstruction gives the complex conjugate $(g' \ast s')^{*}$. Let $G = G' + G''$, then one obtains after passing through the difference the following signal:

$$(s \ast G)' \ast G = (s' \ast G'^{*}) \ast (G' + G'')$$

$$= s' \ast (G'^{*} \ast G') + s' \ast (G'^{*} \ast G'')$$

$$= s' + s' \ast (G'^{*} \ast G'')$$

since $G'^{*} \ast G'$ gives a delta function correlation.

The other signal $s' \ast (G'^{*} \ast G'')$ does not correlate to a delta function and therefore amount to noise, which we shall call $N$. The reconstructed signal is then of the form

$$f'[s \ast g] = s' + N$$

The signal to noise ratio, assuming $s' \sim s$, is then

$$\frac{s}{N} = \frac{\frac{\omega_2 - \omega_1}{2 \omega_m}}{1 - \frac{\omega_2 - \omega_1}{2 \omega_m}} = \frac{\omega_2 - \omega_1}{2 \omega_m + \omega - \omega_2}$$

Thus the reconstruction will be noisy if $2 \omega_m$ is much greater than $\omega_2 - \omega_1$. Practically, $s'$ should be nearly as good as $s$ if the bandwidth of $s$ is considerably less than $\omega_2 - \omega_1$.

29 December 1965

Jurus Uptik, 29 December 19
Experiments with phase-encoded reference beam

Experiments were done with the permanently assembled optical system for making phase-encoded holograms. The fixed mounting of the hologram was replaced by a mount with vertical, horizontal, and rotational adjustment since it was found that the hologram could not be replaced with sufficient accuracy. The optical system used was the following:

Two holograms were made on 23 December 1965 with diffusers in the reference beam in position #2.

- **Hologram #1**: $7 \times 10^{-2}$ ref. \"A\" in pos. #2, 8 sec. (exp. good)
- **Hologram #2**: $6 \times 10^{-3}$ ref. \"B\" in pos. #2, 8.5 sec. (exp. good)

Both holograms gave readable reconstructions when properly adjusted. Diffuser \"A\" is a piece of etched glass with normal laser dispersion; diffuser \"B\" is opal glass with approximately equal dispersions in all directions. The estimated maximum spatial frequency

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Juris Upatnieks, 28 December 1965
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28 December 1965

Content of the reference beam with diffuser "D" was 250 l/min, and that for diffuser "D" lower. The reconstructed images were recorded on film:

Film recordings (sheet #15, 27 Dec. 1965):

#5 Reconstruction from hologram #1 with diffuser "D". Exp. times: 1, 3, 12, 30 sec. (attenuated in light beam).

#6 Reconstruction from hologram #2 with diffuser "D". Exp. times: 3, 12, 30, 90 sec.

To make the reconstruction completely disappear, hologram #1 had to be misaligned by about 40 µm, either up or sideways; hologram #2 had to misaligned by about 20 µm.

Difficulties were encountered in aligning the holograms: usually only a kind of letters could be reconstructed at a time instead of the whole image. It was found that rotation of the hologram around vertical axis would correct this. The rotation apparently corrects for a horizontal scale error, which in turn might be caused by shrinkage of the emulsion when drying. Different part of the hologram reconstruct with different brightness, apparently also caused by shrinkage of emulsion.

Juris Uptatriks, 28 December 1965
Change in wavelength at which hologram reconstructs due to changes in angle of incidence.

To calculate the effect of changing the angle of incidence of light on a hologram, it is sufficient to consider two reflective layers within the emulsion. The layers are produced by interference in the hologram making process.

\[ a = \text{angle of incidence} \]
\[ b = \text{spacing between layers} \]
\[ D = \text{total path difference} \]

\[ D = 2 \frac{b}{\cos \alpha} - a \sin \alpha \]

\[ a = 2b \tan \alpha \]

\[ D = \frac{2b}{\cos \alpha} - 2b \sin^2 \alpha = \frac{2b}{\cos \alpha}(1 - \sin^2 \alpha) \]

\[ D = 2b \cos \alpha \]

Therefore, path length decreases with increasing angle of incidence, and the hologram will reconstruct at shorter wavelengths.

Juris Ulpatveiks, 4 January 1966
6 January 1966

Holograms with phase-encoded signal beam.

Several holograms were made with the fixed assembly, and using etched glass and opal glass having different dispersion characteristics. The data on holograms are as follows (all holograms were made on 5 January 1966):

<table>
<thead>
<tr>
<th>Hologram #</th>
<th>Intensity of light</th>
<th>Type of diff.</th>
<th>Exp. time</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>$35 \times 10^{-4}$ ref.</td>
<td>Diff. &quot;A&quot; in pos. #3</td>
<td>10 sec.</td>
<td>Exp. O.K. but dark</td>
</tr>
<tr>
<td></td>
<td>$38 \times 10^{-4}$ signal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td>$11 \times 10^{-4}$ ref.</td>
<td>Diff. &quot;B&quot; in pos. #3</td>
<td>40 sec.</td>
<td>Exp. O.K. but dark</td>
</tr>
<tr>
<td></td>
<td>$10 \times 10^{-3}$ signal</td>
<td>Diff. &quot;C&quot; in pos. #4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td>$25 \times 10^{-4}$ ref.</td>
<td>Diff. &quot;D&quot; in pos. #3</td>
<td>3½ min.</td>
<td>Exp. good</td>
</tr>
<tr>
<td></td>
<td>$25 \times 10^{-4}$ signal</td>
<td>pos. #4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Holograms #1 & #2 diffracted intense light, hologram #3 somewhat less.

Jaris Upatnickus, 6 January 1966

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7 January 1966

Reconstruction from holograms with phase-encoded signal beam.

Hologram #1 above was reconstructed and image photographed on Pan-X film, developed in the usual manner. Two different areas of the hologram were used. The larger area, or aperture, produced much better signal to noise ratio than the small aperture.

Jaris Upatnickus, 7 January 1966
Film recordings show (sheet #16, 6 Jan. 1966):

#1 Reconstruction from hologram #1 of 5 Jan. 66. 25 mm diameter aperture at hologram, 152 mm camera lens used to focus light, set at f-5.6. Exposure times: ½ s, ⅛ s, ⅛ s, ⅛ s, ½ s; best exp. ⅛ s.

#2 Reconstruction from hologram #1 of 5 Jan. 66. 10 mm diameter aperture at hologram, 152 mm camera lens used to focus light, set at f-14. Exposure times: ½ s, ⅛ s, ⅛ s, ⅛ s; best exp. ½ s.

Attempts were made to reconstruct holograms #2 and #3 of 5 Jan. 66, but image could not be obtained. Apparently something was misaligned in the system.

Juris Upatnieks, 7 January 1966

1 January 1966.

On the reconstruction of hologram with reference beam from the back side consider the hologram of a single point:

![Hologram diagram]

Juris Upatnieks, 7 January 1966
The fringes form in the three-dimensional recording medium as indicated in the diagram. On reconstruction, the virtual image appears:

One should note that the reconstruction is caused by reflection off the three-dimensional interference pattern, rather than by diffraction. Since all wavelengths of light are reflected in the same manner, the image should reconstruct with white light, without any decrease in the quality of the image. The multiple layers of reflecting surfaces in the recording medium, however, act as a interference filter, and thus the reconstructed image appears to be monochromatic. Actually, a band of frequencies are selected by the "filter".

The image reconstructed in white light should be just as sharp as one reconstructed in monochromatic light.

Juris Ulpiants, 27 January 1985
Recording of fringes in 3-dimensional medium, from geometrical considerations.

Spacing of planes of equal intensity:

\[ \frac{\lambda}{2 \lambda_s} = \sin \left( \frac{\theta}{2} \right) \quad \text{or} \quad \lambda_s = \frac{\lambda}{2 \sin \left( \frac{\theta}{2} \right)} \]

where \( \lambda \) is the wavelength of light inside the recording medium; \( \lambda_s \) is the spacing between planes of equal intensity, also special wavelength.

\[ \lambda_s' = \frac{\lambda_s}{\cos \phi} \]

\[ \lambda_s = \frac{\lambda}{2 \cos \phi \sin \left( \frac{\theta}{2} \right)} \]

\( \lambda_s' \): special wavelength measured along the surface of the recording medium.

Jures Elpatricks, 10 February 1966
\[ \theta_n = \text{angle of reference beam to } L \text{ of recording medium} \]
\[ \theta_s = \text{angle of signal beam to } L \text{ of recording medium (signal being our plane wavefront)} \]

\[ a = \frac{L}{\cos \psi} \]
\[ b = a \sin \left( \frac{\theta_n + \theta_s}{2} - \psi \right) \]
\[ b = \frac{L}{\cos \psi} \sin \left( \frac{\theta_n + \theta_s}{2} - \psi \right) \]

Let \( N \) = \# of planes intersected by diffracted ray in direction \( \psi \), of wavelength \( \lambda' \)

Then \[ N = \frac{b}{\lambda_s} \]

\[ \Delta \lambda = \lambda' - \lambda = \frac{\lambda'}{N} = \frac{\lambda_s \lambda'}{b} \]

Let \( \alpha = \theta_n - \theta_s \), then

\[ \Delta \lambda = \frac{\lambda \lambda'}{2L \sin \left( \frac{\theta_n + \theta_s}{2} \right) \sin \left( \frac{\theta_n + \theta_s}{2} - \psi \right)} \]

If \( \psi = \theta_s + \psi' \) and \( \psi' \) is small, and if \( \lambda \ll \lambda' \), then

\[ \Delta \lambda = \frac{\lambda^2 \cos \theta_s}{2L \sin^2 \frac{1}{2} (\theta_n - \theta_s)} \]

Jenius Upatnick, 10 February 1966
22 February 1966

Holograms made with reference beam introduced from the back side.

A number of holograms were made with the reference beam introduced from the back side of the photographic plate. A laser with 6328Å light was used to make them, and the optical system shown below was used:

Perkin-Elmer model 5300 laser

![Diagram of hologram setup](image)

The following holograms were made:

<table>
<thead>
<tr>
<th>Date</th>
<th>Light intensity</th>
<th>Exp. time</th>
<th>Development</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>26 Jan '66</td>
<td>28x10^4 W/m²</td>
<td>190 sec.</td>
<td>Standard (6 min. D19, then fixed)</td>
<td>Exposure too dark, pair reconstruct well</td>
</tr>
<tr>
<td>26 Jan '66</td>
<td>none</td>
<td>190 sec.</td>
<td>Standard, then bleached</td>
<td>Very weak reconstructs</td>
</tr>
<tr>
<td>27 Jan '66</td>
<td>11x10^4 W/m²</td>
<td>160 sec.</td>
<td>Standard</td>
<td>Exposure dark (3% transmission, reconstruction is fair)</td>
</tr>
</tbody>
</table>

Janes Uptonwick, 22 February 1966
<table>
<thead>
<tr>
<th>Date</th>
<th>Light intensity</th>
<th>Exp. time</th>
<th>Development</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$14 \times 10^{-7}$ mig.</td>
<td></td>
<td></td>
<td>Some as above. Previous poorly reconstructed plates appear to have vibrate.</td>
</tr>
<tr>
<td>28 Jan 66</td>
<td>#1 $18 \times 10^{-7}$ ref.</td>
<td>45 sec.</td>
<td>Standard, no fixing</td>
<td>Exp. light, reconstr. weak.</td>
</tr>
<tr>
<td></td>
<td>#2 $18 \times 10^{-7}$ mig.</td>
<td>90 sec.</td>
<td>Standard, no fixing</td>
<td>Exp. dark, plate vibrating, reconstr. good around edges.</td>
</tr>
<tr>
<td>31 Jan 66</td>
<td>$17 \times 10^{-7}$ ref.</td>
<td>90 sec.</td>
<td>Standard, no fixing</td>
<td>Exp. good (10% transm.), reconstr. very good.</td>
</tr>
<tr>
<td></td>
<td>$16 \times 10^{-7}$ mig.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Feb 66</td>
<td>#1 $19 \times 10^{-7}$ ref.</td>
<td>100 sec.</td>
<td>Standard, no fixing, plate bleached</td>
<td>Exp. good, dark reconstr. very good.</td>
</tr>
<tr>
<td></td>
<td>$10 \times 10^{-7}$ mig.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Feb 66</td>
<td>#3 $18 \times 10^{-7}$ ref.</td>
<td>70 sec.</td>
<td>Standard, no fixing</td>
<td>Exp. good, 16% transmission, reconstr. very good.</td>
</tr>
<tr>
<td></td>
<td>$6 \times 10^{-7}$ mig.</td>
<td>150 sec.</td>
<td>#3</td>
<td>Subject: train moved during exp. Reconstructed poor, 5% transmission.</td>
</tr>
<tr>
<td>2 Feb 66</td>
<td>#4 $18 \times 10^{-7}$ ref.</td>
<td>130 sec.</td>
<td>#4</td>
<td>Subject: train, reconstr. well, 7% transm.</td>
</tr>
<tr>
<td></td>
<td>$7 \times 10^{-7}$ mig.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Feb 66</td>
<td>#1 $19 \times 10^{-7}$ ref.</td>
<td>100 sec.</td>
<td>#1</td>
<td>x = 32°, d = 75 cm. Exp. good, reconstr. weak.</td>
</tr>
<tr>
<td></td>
<td>$10 \times 10^{-7}$ mig.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Feb 66</td>
<td>#2 $20 \times 10^{-7}$ ref.</td>
<td>125 sec.</td>
<td>#2</td>
<td>Reconstruction good, exp. good.</td>
</tr>
<tr>
<td></td>
<td>$8 \times 10^{-7}$ mig.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** on all above holograms, $\alpha = 15°, \beta = 4°, d = 95$ (Sinjuris Upatrick's notation).

Light meter calibration: $25 \times 10^{-2} = 0.07$ watts/cm².

Required exp. for 25% is 8000 erg/cm².
22 February 1966

Vibration of the 6" thick photographic plate was a major problem and apparently affects the brightness of the reconstructed image even when the image appears to be good. Shrinkage of the developed emulsion is reduced considerably if the plate is not fixed. Fixed plates reconstructed from bluish-green to violet colors, the unfixed ones from orange to dark green. Good reconstruction were obtained using either mercury arc or girkonium arc light sources without filters. Better, cleaner images were obtained with an interference filter.

Since all the images recorded on a photographic plate reconstruct simultaneously, obviously images on both sides of the plate will also reconstruct simultaneously. Thus, for example, image over 360° field of view can be recorded on one plate if the reference beam is brought in from above or below (360° measured in horizontal plane).

James Upatnieks, 22 February 1966
24 February 1966

Reconstruction of images from holograms made with the reference beam from the back side.

Reconstructions were made with the following optical system using high-pressure mercury arc source of light:

The hologram was rotated to give best reconstruction for each color of light, and the camera was adjusted each time to get the best view.

Reconstructions made on 31 January 1966's (from hologram #4 of 31 Jan).

<table>
<thead>
<tr>
<th>Negative</th>
<th>Filter</th>
<th>f - ve of lens</th>
<th>Exp. time</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>44°</td>
<td>yellow (579 mp)</td>
<td>f - 8</td>
<td>10 sec.</td>
</tr>
<tr>
<td>#2</td>
<td>44°</td>
<td>red (600 mp)</td>
<td>f - 8</td>
<td>4 sec.</td>
</tr>
<tr>
<td>#6</td>
<td>67°</td>
<td>green (546 mp)</td>
<td>f - 8</td>
<td>25 sec.</td>
</tr>
<tr>
<td>#8</td>
<td>67°</td>
<td>none</td>
<td>f - 8</td>
<td>10 sec.</td>
</tr>
</tbody>
</table>

Reconstructions made on 1 Feb. 1966: (from hologram #4 of 1 Feb '66)

| #1       | 37°    | yellow (579 mp) | f - 8     | 10 sec. | Train |
| #2       | 37°    | no filter       | f - 8     | 5 sec.  | Train |
| #4       | 37°    | green (546 mp)  | f - 8     | 10 sec. | Train |
| #3       | 37°    | no filter       | f - 8     | 20 sec. | Train |

James Upatnieks, 24 February 1966
Reconstructions made with zirconium arc light source, on 1 Feb. 1966. (Hologram made 31 Jan. 66)

<table>
<thead>
<tr>
<th>Negative #</th>
<th>Angle (°)</th>
<th>Filter</th>
<th>f-no. of lens</th>
<th>Exp. time</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>#5</td>
<td>27°</td>
<td>none</td>
<td>f-8</td>
<td>20 sec.</td>
<td>Zirconium</td>
</tr>
<tr>
<td>#6</td>
<td>41°</td>
<td>yellow (579μm)</td>
<td>f-8</td>
<td>40 sec.</td>
<td>Zirconium</td>
</tr>
</tbody>
</table>

Optical system for reconstruction in zirconium arc light:

Reconstruction made in sunlight in 1st week of Feb. 1966.

| #1         | no filter | reconstruction orange | f-8 | 100 sec. | Zirconium |
| #2         | same      | f-11                |     | 100 sec. | Zirconium |

Reconstructions made from hologram of 31 Jan. 1966

Holograms reconstructed with zirconium arc, on 16 Feb. 1966, from hologram of 31 Jan. 1966:

<table>
<thead>
<tr>
<th>Apparent color of image</th>
<th>Filter</th>
<th>f-no. of lens</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1 green</td>
<td>none</td>
<td>f-8</td>
<td>Zirconium</td>
</tr>
<tr>
<td>#2 green</td>
<td>5460Å, 80Å, 155Å</td>
<td>f-8</td>
<td></td>
</tr>
<tr>
<td>#3 yellow</td>
<td>none</td>
<td>f-8</td>
<td></td>
</tr>
<tr>
<td>#5 orange</td>
<td>5790Å, 80Å, 155Å</td>
<td>f-8</td>
<td></td>
</tr>
</tbody>
</table>

Juris Ulpatricks, 24 Feb. 1966
Characteristics and uses of three-dimensional Fresnel zone plates.

If a plane wavefront and a spherical wavefront interfere, the resulting interference pattern in one plane is a Fresnel zone plate. If this pattern is recorded in medium sufficiently thick, then the recording has to be analyzed considering the third dimension too. This type of Fresnel zone plate, recorded in three-dimensional medium, has some interesting properties. The optical system for making the zone plate is as follows:

![Diagram of optical system for making zone plate]

Usually, z₀ is made near infinity by inserting another lens between the recording medium and pinhole, or z₀ can be negative. Orientation of the recording medium can vary.

In use, the zone plate would be used as follows:

![Diagram of zone plate in use]

Consider the following special cases:

1. Let z₁ be negative, and let z₂ = -z₁. In this case, the hologram (Fresnel zone plate) will reconstruct the image point without aberrations and at the wavelengths at which the plate was made.

Juris Upatnieks, 1 March 1966
If the recording medium is thick, the zone plate will act as a filter and image a limited B.W. of wavelength the width of band depending on thickness of recording medium. Any point off axis but in front of being 2.E = 2.O, will reconstruct but with smaller effective aperture of the zone plate, thus attenuating the aberrations ordinarily present in this case. If these points are not monochromatic, each part of zone plate will reconstruct (four) different colors. The aberration for these colors might be smaller.

If a point is moved off axis, again aberrations will increase but brightness of imaged point decrease.

In general, if the object point is illuminated by some wavelength at that at which the hologram was made and there is no shrinkage, such hologram will attenuate any point elsewhere than where it gives aberration-free image.

2. Let Z. be negative recording medium does not shrink and same wavelength of light is used.

This type of zone plate could be used to as a range and direction finder. The optical system is as follows:

The diffracted light from point Q is observed at some plane where the point is not in focus, for example at P. For various positions of point Q the following light distributions would be obtained.

Janis Uptniks, 1 March 1966
At (a) above, all area is uniformly bright. At (b), $\theta \neq 0$
but point is on axis. Near the edges of the plate,
the rays from 2 arrive at wrong angle and are attenuated.
At (c), point 2 is off axis and $\theta \neq 0$, therefore some
rays off the center arrive at proper angle. At (d),
$\theta = 0$ and the point is slightly off axis. As the point
moves toward axis, intensity increases until maximum
as shown at (a). Dividing these characteristics, separation
and orientation between points 1 and 2 and the plate can
be accurately determined.

3. Same as 2, but $Z_0 = \infty$. No restrictions other
   to 3.$
   This plate has similar characteristics to that
   above. Since case (a) is obtained when point 2
   is at infinity, this could be used to
determine a collimation, or to collimate, a
light source with appropriate lenses.

4. Same as 2, but $Z_0 = \infty$ and $Z_1 = \infty$

Some characteristics as 2. Starting with a collimated,
white light source, this type of three-dimensional
grating can be used as a very narrow-band interference
filter. If the source is extended in size, in one
dimension it can pick out a narrow line without
the help of a slit. This would give a sharper and
less expensive filter than conventional interference
filters.
In figures (b) and (c), the width of the peaks depends on how far the point is away from its optimum position in direction off-axis along the axis. The amplitude at the center, point 'C', is a function of how far point A is off in direction 1 to the axis.

A number of such interference patterns can be superimposed, resulting in a superposition of previously described characteristics.

Juris Uptāničs, 1 March 1966

4 March 1966

Emulsion thickness measurements.

Emulsion thickness, and its change due to processing, has great effect on the reconstructed image when a hologram is made with a large angle between the reference and signal beams. In order to predict the behavior of such a hologram, emulsion thickness must be known. The diagram on the next page shows the optical system for measuring the emulsion thickness.

The measurements so far have been somewhat inconsistent. Thickness of the 4x5x2 plate with 649F emulsion has been measured to lie between 12.4 and 15.8 μ, depending on plate and processing. Thickness may depend on processing, humidity of air, exposure, and variations in production. Further tests will be made.

Juris Uptāničs, 4 March 1966
All of the above components were mounted on a 24 x 24 x 4 in surface plate.

Measurements were made as follows: a reference fringe was found on the clear side by observing white-light fringes; then interference filter was inserted, stage moved and fringes counted until clear (good contrast) fringes were observed on the other side, and finally filter was removed and reference fringe moved to same location. Thickness $h$ is then equal to:

$$h = \frac{N}{2} \lambda,$$

where $N$ is number of fringes, and $\lambda$ is the wavelength of light with filter in place.

Juriis Upatnieks, 4 March 1966.
8 March 1966

Introduction of reference beam at near 90° angles.

It may be desirable to have the reference beam enter the emulsion at nearly 90° angle of incidence. This may be desirable, for example, when several photographs are superimposed and readout of one at a time is desired. Orientational sensitivity is maximum near 90° internal angle of incidence. Ordinary internal angles of incidence are less than 40°, for this is the cutoff angle for glass with index of refraction of 1.52.

This limitation can be overcome with the scheme as shown below, using a prism and liquid matching the index of refraction of glass:

With this arrangement, the unavailable region of internal angles between 41° and 139° can be reached. The emulsion may be toward the prism also, and the object may lie on either, or both, sides of the plate-prism combination.
Experiments with superimposed, 3-D Fresnel zone plates.

It is known that a Fresnel zone plate, made from an interference pattern of two beams of light, will image an object point without distortion or aberrations for at least one point in space. In the nearby area, aberrations may be small. The area, or rather volume, over which aberrations are negligible, can be extended by recording several zone plates, each effectively acting in a different direction. This was tested experimentally using the following optical system:

A plate was made with 3 Fresnel zone plates superimposed, on 8 March 1966:

- $37 \times 10^2$ converging beam
- $45 \times 10^2$ diverging beam

Exp. 3 times @ .20 sec. each

$\theta = 15^\circ, 20^\circ, 25^\circ$

Processing:
- Developed 6 min in 0'-19', washed 4
- Fixing

Juris Upatnieks, 10 March 1966
10 March 1966

To test the quality of the plates, the converging beam was blocked and point focuses of the imaged diverging beam were observed. The zone plate gave diffraction-limited point images for the exact three angles of 0° = 25°, 40° and 25°; for ½° either way from these angles, the point image was still nearly perfect; for other angles, astigmatism became quite large. Except of the unwanted zone plate image was good at the exact values of 0. At halfway points, 17.5° and 22.5°, interference patterns between the waves diffracted by each zone plate could be observed. The interference pattern had a complex pattern, indicating large aberrations.

Two plates could be superimposed on same axis but having different convergence of one of the two beams.

Janis Upatnickis, 10 March 1966

29 March 1966

Color holograms with reference beam from the back side.

A number of holograms were made with three colors using the red line from a helium-neon laser, and the green and blue lines from the argon laser. The holograms were superimposed in sequence on a single photographic plate. The first successful hologram with all three colors was made on about March 19, 1966. The quality however has not been very good since the intensity of reconstructed image has been quite low compared to the scattered light off the surface of the glass plate.

Janis Upatnickis, 29 March 1966
29 March 1966

Other difficulties were encountered causing inconsistent results. On several occasions two of the colors have reconstructed, while the third has been absent. The reconstructions have had varying intensities for identically exposed holograms. A search for causes of these results have led to a recognition of the following problems:

1. Short coherence length of green and blue laser lines. The coherence length can be increased by decreasing the power output, and its effect by selecting subjects that are not large.

2. Low frequency vibrations. These vibrations are transmitted by foundations of the buildings and supports of the granite blocks. The grate block supported on air was well isolated from these vibrations.

3. Audio frequency vibrations transmitted by air. These vibrations were observed on an oscilloscope by detecting variations in interference fringes with a photomultiplier tube. A speaker connected to an audio oscillator gave a variable source of vibrations. The \( \frac{3}{4} \times \frac{3}{4} \times \frac{3}{4} \) in. and \( \frac{5}{4} \times \frac{5}{4} \times \frac{5}{4} \) in. glass plates both had resonant frequencies at about 1000 to 3000 cps. range. The greater inch thick plate had lower amplitude of vibration. The fans behind the organ laser caused considerable vibration. An enclosure will be made to reduce audio vibration intensity.

It appears that vibrations are the cause of poor quality reconstructions. Optical system used for making holograms is shown on the next page.

Juris Ilgatsvīts, 29 March 1966
29 March 1966

Mirror adjusted to bring one or the other laser beam into the system.

Jenis Ulpsnirks, 29 March 1966

14 April 1966

Reconstruction of holograms with low-pressure mercury arc source.

Excellent reconstructions of holograms have been obtained with the green (546 A) line of a low pressure mercury arc source, GE-100 W lamp. To visual appearance, the reconstruction is as good as with a laser, and nearly as bright as 4 x 5 in. hologram illuminated with 8 mW laser. The brightness is achieved by using a large-size pinhole which does not degrade the image quality seriously since the eye inherently

Jenis Ulpsnirks, 14 April 1966
14 April 1966

The resolving power to begin with, about 1 min. of an arc or $3 \times 10^{-4}$ radians. Reasonably good images can also be seen with the yellow mercury line if the offset angle is not large, under say 30°. At higher angles the double yellow line causes double images to appear. Mercury arc lamps, as well as other similar incoherent light sources, are especially well suited for hologram reconstruction since they have most of the energy concentrated at a few spectral lines, and each line is quite narrow. Ordinary, front reference beam holograms can be viewed if a filter is used to reject the other mercury lines; holograms with reference beam from the back side can be also viewed without the filter and give extremely sharp image. Holograms with reference beam from the front but with large offset can be used without a filter since the hologram itself acts as a filter. By rotating the hologram, reconstructions can be observed in the green, yellow, or violet lines of the source.

Here are calculations on the expected degradation of image quality when viewed with a mercury source. A typical arrangement for viewing holograms is shown below:

\[ a = \text{pinhole size} \]
\[ \theta = \text{angle between illuminating beam and } \perp \text{ to the plate} \]

From coherence length (measurements of the lamp, $\lambda = 4000 \AA$, and using coherence length eq. $\lambda_c = \frac{(2\pi)^2}{\lambda^2}$, we can calculate $\theta$ to be:

Juris Uptniks, 14 April 1966
14 April 1966

\[ \lambda = \frac{(d \lambda)^2}{d^2} = \frac{(5461)^2}{4000 \cdot 5461} = 1.4 \, \text{Å} \]

From the grating eq. \( \lambda s \left( \sin \theta_1 - \sin \theta_2 \right) = \lambda x \), and letting \( \theta_2 = 0 \), \( \theta_1 = 45^\circ \), \( \lambda s = 5461 \, \text{Å} \), we can calculate \( \theta_0 \):

\[ \lambda s \, \sin (\theta_1 + \theta_0) = \lambda s \left( \sin \theta_1 \cos \theta_0 + \cos \theta_1 \sin \theta_0 \right) \approx \lambda s \left( \sin \theta_1 \cos \theta_0 \right) = \lambda s \cos \theta_0 \]

\[ \theta_0 \approx \frac{\lambda x}{\lambda s} \cos \theta_1 = \frac{1.4}{5461 \cdot (0.707)} \approx 3.6 \times 10^{-4} \, \text{rad} \]

This is approximately the same as the resolution limit of the eye. Assuming \( a = \frac{1}{2} \, \text{in.} \), and distance to hologram to be 36 in., the angle of the source at the hologram is:

\[ A_k = \frac{1}{8 \times 36 \times \theta_0} = 3.5 \times 10^{-3} \, \text{rad} \]

Thus \( A_k \) is about ten times larger than the resolution limit of the eye. The degradation of the image is not as great as it may appear, since the inherent graininess of coherent light (when making a hologram) reduces the effective resolving ability considerably. Also, if the hologram is viewed some distance away, then the effect of large source size decreases.

The high pressure mercury arc lamp has \( \lambda = 70\,\text{Å} \) or \( d \approx 80\,\text{Å} \). This means that line width is 50 times that of the low pressure mercury lamp, and would be less suitable for viewing holograms.

Juras Zupatiski, 14 April 1966.
An reconstruction through diffuse media.

On p. 16 of this notebook the conditions under which good reconstructions of the image can be expected were discussed. Several additional considerations will be mentioned here.

First of all, if several successive etched or ground glass plates are used between the object and the hologram plane, then whatever it comes from the previous scattering plate must be considered as the signal for the next one. Consider the diagram below:

[Diagram of hologram and signal sequence]

The signal at $P_1$ is the object, at $P_2$ the light distribution after it has passed through $P_1$, at $P_3$ whatever arrives there, etc. The computation for signal to noise ration must be carried out at each plane, and the overall system performance $S/N$ is then the product of the signal to noise ratios at each plane:

$$N \approx \frac{S_1}{N_1} \cdot \frac{S_2}{N_2} \cdots \frac{S_n}{N_n}$$

If the bandwidth of each plate is small, then addition of other plates may improve the signal to noise ratio since any noise generated by the hologram misalignment would be scattered over a wider angle by the other plates. If the spatial bandwidth is wide, then degradation can be expected. The reason for this degradation is that convolution takes place of the signal arriving at a plane, and the spectrum of the diffuse glass itself. Thus, bandwidth of the convolution may exceed the upper limit of spatial frequencies that can be transmitted by an optical system.

Juris Upatnieks, 15 April 1966
15 April 1966

If we consider the diagram below, then the maximum special frequency $f_m$ that can be transmitted by an optical system is

\[ f_m = \frac{1}{\delta x} \quad \text{where } \delta x \text{ is the wavelength of light.} \]

This sets the upper limit of special frequencies transmitted to another plane in the $Z$ direction. For example, if the light consists of particles of matter size then wavelength of light, then this would be equivalent to having a dielectric plus pulses versus the bandwidth of the system. The system would allow only a limited band of frequencies to pass and receiving of pulses in this identical shape would be impossible. Thus, this type of a system is not reversible. If an optical system is not reversible, then reconstruction of the object through such a system is not possible (noise level would be very high with respect to the signal).

For some systems, the overall system $S$ could be represented by the expression

\[ \frac{S}{S_0} = \left( \frac{S_0}{N_0} \right)^n \]

where $n$ is the number of different, a three-dimensionally distributed scatterer could also be represented by such an expression.

An interesting phenomena takes place if we consider a square wave plane grating.
15 April 1966

If the thickness is such that phase retardation is exactly \( \lambda_0 \) for a wavelength \( \lambda_0 \), then there is no dielectric in the spectrum of this grating. Next, if it is made such that \( d < \lambda_0 \) then there is no transmitted or reflected diffraction light. Thus, such a grating must act as a perfect mirror for \( \lambda_0 \), but not for other wavelengths. If the phase retardation is not, then this type of grating represents a narrow stop filter.

Juris Uptaniets, 15 April 1966.

19 April 1966

Experimental verification of the technique for improving 2-dimensional holograms.

On pages 132 and 133 of computation book #768, the method of using pure phase modulation of two-dimensional objects was described. Experiments were performed to verify these ideas with the optical system shown below:

Juris Uptaniets, 19 April 1966.
19 April 1966

The plate plate was magnified 15x by the optical system, as determined by actual measurement of magnification. The "object" photographed in this case was the clear field (without transparency) of the ground glass. The experiments were performed on 18 April 1966. The following photographs were taken:

<table>
<thead>
<tr>
<th>Photograph #</th>
<th>Exp. time</th>
<th>Description of test conditions</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>1 sec.</td>
<td>Collimating lens out, no diffuser, no wire</td>
<td>Pattern of circles comes from dust and other imperfections of the 100 mm lens</td>
</tr>
<tr>
<td>#2</td>
<td>1 sec.</td>
<td>Collimating lens out, diffuser in focus, no wire</td>
<td>Good focus is over part of photograph; small spots were on microflat glass surface.</td>
</tr>
<tr>
<td>#3</td>
<td>1 sec.</td>
<td>Collimating lens out, diffuser in but film 170.5 cm from lens (11/2 cm out of focus), no wire</td>
<td>Typical grain of diffuser, magnified 15x by lens</td>
</tr>
<tr>
<td>#4</td>
<td>1 sec.</td>
<td>Collimating lens in, diffuser in focus, no wire</td>
<td>Visible patterns for collimating lens. Wire creating does not change effect of diffuser.</td>
</tr>
<tr>
<td>#5</td>
<td>1 sec.</td>
<td>Collimating lens in, diffuser in focus, wire between collimating lens and 7 cm from diffuser.</td>
<td>Wire shows up as noise, soft decrease by diffuser.</td>
</tr>
<tr>
<td>#6</td>
<td>1 sec.</td>
<td>Collimating lens out, diffuser out, wire next to 100 mm lens</td>
<td>Diffraction pattern from wire barely visible.</td>
</tr>
</tbody>
</table>

Juris Upatnieks, 19 April 1966
<table>
<thead>
<tr>
<th>Photograph #</th>
<th>Exp. Time</th>
<th>Description of Test Conditions</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>#7</td>
<td>1 sec.</td>
<td>Collimating lens out, diffuser in focus, wire next to 100 mm lens</td>
<td>Some noise apparent, but effect not very disturbing</td>
</tr>
<tr>
<td>#8</td>
<td>1 sec.</td>
<td>Collimating lens out, stop 170.5 cm from lens (3/4 cm out of focus), wire next to the 100 mm lens</td>
<td>Additional noise is almost completely lost in the noise from diffuse itself</td>
</tr>
</tbody>
</table>

These tests clearly indicate that the effect of imperfection in a coherent optical system can be greatly reduced by phase-modulating a transparency. It is also important that the phase plate is precisely in focus, that the illuminating beam of the phase plate is uniform, and that the transparency is in the same plane as the phase plate (right next to it or in the imaged position of the phase plate). If these conditions are not met, then inferior results will be obtained. It is important also that the optical system images all of the scattered light, or records it in the case of a hologram. Restriction of aperture may result in noise. In the experiment performed, the liquid probably did not exactly match the glass and thus complete phase correction for one side of the etched glass did not take place, introducing some nonuniformity. The following photograph shows the effect of restricted aperture:

#9 2 sec. exp. Collimating lens out, diffuser in focus, no wire, 100 mm lens set at f-5.6

Light from one corner is cut off at the other. Uniformity is good.
Experiments with phase-encoded transparencies. Experiments to further test & phase-modulated transparency were made, similar to those on pp. 35-37 of this notebook. Actual transparencies were imaged in this case through an optical system consisting of several lenses. The system used is shown below.

The following photographs were taken on 20 April 1966:

<table>
<thead>
<tr>
<th>Photograph</th>
<th>Exp. time</th>
<th>Description of test conditions</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>#2</td>
<td>1/2 sec.</td>
<td>Diffuser + transparency in focus</td>
<td>Image good at center</td>
</tr>
<tr>
<td>#3</td>
<td>1/2 sec.</td>
<td>Diffuser out, transparency out</td>
<td>Diffraction pattern from light + dirt visible all over</td>
</tr>
<tr>
<td>#4</td>
<td>1/2 sec.</td>
<td>Diffuser out of focus, transparency in focus</td>
<td>Grain from diffuser visible</td>
</tr>
<tr>
<td>#5</td>
<td>2 sec. exp.</td>
<td>Diff. in focus, transp. in focus.</td>
<td>Some intensity variations from phase plate are visible</td>
</tr>
<tr>
<td>#6</td>
<td>1 sec.</td>
<td>Diffuser out of focus, transp. in focus.</td>
<td>Diffraction pattern from dirt obscure image</td>
</tr>
<tr>
<td>#7</td>
<td>2 sec.</td>
<td>Diffuser out of focus, transp. in focus.</td>
<td>Image has going appear</td>
</tr>
</tbody>
</table>

Juris Juraevs, 27 April 1966
<table>
<thead>
<tr>
<th>Photograph #</th>
<th>Exp.</th>
<th>Description of test conditions</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Subject: Monograph, dark letters on transparent background</td>
<td></td>
</tr>
<tr>
<td>#8</td>
<td>1/30s</td>
<td>Diffuser + slide in focus.</td>
<td>Same variation in intensity as visible.</td>
</tr>
<tr>
<td>#9</td>
<td>1/6s</td>
<td>Diffuser out of focus, slide in focus</td>
<td>Grain very pronounced and annoying.</td>
</tr>
<tr>
<td>#10</td>
<td>1s</td>
<td>Diffuser out, slide in focus</td>
<td>Diffraction patterns form background</td>
</tr>
</tbody>
</table>

The size of the portrait was 2.1 cm across the head (ninth). The monograph was approximately same in length. It appears that some residual amplitude modulation was present even when diffuser was in focus. This is probably because both sides of the diffuser plate were etched and the liquid used to smooth one side did not match exactly the glass.

Juris Upatnieks, 27 April 1966
25 May 1966

Coherence in coherent optical systems

Imaging of a diffusely reflecting or transmitting surfaces nearly always produces an image that is
grain in appearance. From experiments it is
known that a larger aperture (i.e., larger) optical
system will give finer grain pattern,
and thus be less objectionable. The cause of this
grainy appearance will be discussed here.

For simplicity of analysis, consider the
optical system:

![Optical System Diagram]

The signal in this case is a pure plane function
\( s(x, y) = a_0 \exp(i \phi(x, y)) \). The transfer function of the
optical system (this particular one or any other) is
\( g(x, y, x', y') \). The output of the system at plane

\( P_2 \) is then given by

\[
i(x, y) = s * g = \int \int s(x, y) g(x-x', y-y') \, dx \, dy
\]

\[
= a_0 \int \int \exp(i \phi(x, y)) g(x-x', y-y') \, dx \, dy
\]

This integral shows that the output intensity, \( I(x, y) \),
depends on the averaging, or integration, of the
vector \( i \phi(x, y) \) over the area of the transfer function.
If the phase of \( s(x, y) \) does not vary a great deal
over the area of integration, then \( I(x, y) \) remains
constant, and grainy appearance is absent. If the
phase varies considerably over the area of integration,

Junis Upatnieks, 25 May 1966
One-dimensional phase variations of etched glass. Amplitude = a.

then \( i(x,y) \) can be expected to vary too and thus amplitude variations exist at the output even if they were absent at the input. This is the case for finely ground glass, and for diffusely reflecting surface, since in both of these cases only phase variations exist at the surface.

Mathematically, we can distinguish two cases:

**Case 1:** Phase variation small over area of integration. Then the approximation

\[
\phi(x,y) = \delta(x-g, y-h)
\]

can be made. The output then is

\[
i(x,y) = \int \int 2 \pi \delta(x-g, y-h) \, dx \, dy = 2 \pi \delta(x-g, y-h)
\]

**Case 2:** Phase variations are large over area of integration. For a one-dimensional case, see graph above. If the effective width of integration is \( d \), and maximum spatial frequency content of \( x(x,y) \) is \( f_d \), then phase variations are significant in producing amplitude variations at the output if \( f_d > \frac{1}{d} \). For diffraction-limited optical system, the transfer function is a Bessel function

\[
g(x-g, y-h) = k \, J[k_2(x-g), k_3(y-h)]
\]

For other optical systems, the transfer function might be more complex.

Juris Upatnieks, 25 May 1966
Comparing this with incoherent optical systems, the signal \( s(x,y) \) is considered to be a scalar. Therefore, the image of a clear field will always be of uniform intensity, as the image of detail will be slightly less sharp.

In order to image a phase-varying field with constant amplitude faithfully, the spatial frequency content of the signal must be less than the bandwidth of spatial frequencies that the optical system can reproduce. This is true whether the imaging is done by lenses holographically, or by the lens of the eye.

For the case where the phase-varying plane is out of focus, we can first find the signal at the plane which is imaged:

\[
i(x,y) = \int \frac{i(x',y')}{O(x,y)} \, dx' \, dy'
\]

It is known that this integral gives a phase &\#x00A0;varying \& signal. The image \& is then similar, or

For the case where the phase-varying plane is out of focus, we can first find the signal at the plane which is imaged:

\[
i(x,y) = \int \frac{i(x',y')}{O(x,y)} \, dx' \, dy'
\]

It is known that this integral gives always a phase-varying signal. The image \& is then similar, or

Janis Upatnicks, 25 May 1966
Uses of phase-modulated coherent light with time as one variable.

Usually any change in phase due to changes in effective path length of light is undesirable when making holograms. A deliberate phase change as a function of time can be introduced in, for example, the reference beam to achieve special effects.

One use would be in conjunction with vibration measurements using the hologram technique. When observing or recording the vibration pattern, one beam of light could be phase modulated at the same frequency as the vibration of the object whose vibrations are measured. If the phase is then properly adjusted, the new point can be shifted from a stationary part of the object to one which is moving. This may be especially desirable if the amplitude of vibration is many wavelengths so that the contrast of the fringes becomes very weak. The reference point can then be shifted, and if the phase modulation is calibrated, then accurate measurement is still possible. This diagram illustrates one possible arrangement:

![Diagram of hologram setup](image)

Note: Mirror 1 or 2 is moved at some rate or object is vibrating and both are phase locked (excited by some source of energy).

Juris Uptinis, 3 June 1966
Another application would be to change the path length of the reference beam by the same amount as the path length of the signal is changing due to vibration of the object. A detector would have to be installed to determine the motion of the object, and this signal would then be fed into a servo amplifier that in turn would change the reference beam path length. This scheme would work for the whole object only if it vibrated as a whole.

If a laser were available where it could be changed continuously by any desired amount, then this could be used in the following ways:

1) Compensate for one particular point in the above two cases, by making \( \frac{\Delta L}{L} = \text{constant} \) for some point.

2) Determine the \( \Delta L = 0 \) point by making \( \alpha \) be a function of time. Fringes then could be observed only where path length difference is zero, or \( \Delta L = 0 \).

3) Make both \( \alpha \) and \( \Delta L \) functions of time, then if one is known, the other can be found from relation \( \frac{\Delta L}{L} = \text{constant} \).

Juris Upatnieks, 3 June 1966
Emulsion thickness measurement of the CFF emulsion on 4x5x½-in. glass plate.

A series of measurements were made using the optical system shown on p. 25. In order to reduce the effect of emulsion thickness variations from plate to plate, one plate was cut in several pieces and each piece processed in a different way. It was found, however, that even emulsion on one plate may vary as much as 2µ. Thus, the test results are difficult to interpret. Small variations in thickness could be the result of uneven emulsion coating. Three readings were taken for each case and the average taken. The table below summarizes the test results.

<table>
<thead>
<tr>
<th>Plate Identification</th>
<th>Processing and handling of plate</th>
<th>1 hr. after</th>
<th>24 hrs. after</th>
</tr>
</thead>
<tbody>
<tr>
<td>I - A</td>
<td>Exposed, developed, washed</td>
<td>16.1 µ</td>
<td>15.8 µ</td>
</tr>
<tr>
<td>I - B</td>
<td>Unexposed, developed, washed</td>
<td>15.4 µ</td>
<td>15.1 µ</td>
</tr>
<tr>
<td>I - C</td>
<td>Exposed, developed, fixed, washed</td>
<td>15.7 µ</td>
<td>15.2 µ</td>
</tr>
<tr>
<td>I - D</td>
<td>Unexposed, developed, fixed, washed</td>
<td>15.5 µ</td>
<td>13.3 µ</td>
</tr>
<tr>
<td>II - A</td>
<td>Unexposed, developed, washed</td>
<td>17.3 µ</td>
<td>16.9 µ (fixed) 17.6 µ (H2, 25°C)</td>
</tr>
<tr>
<td>II - B</td>
<td>Unexposed, developed, stop-bath washed</td>
<td>15.5 µ</td>
<td>16.9 µ (fixed) 15.7 µ (15°C)</td>
</tr>
<tr>
<td>II - C</td>
<td>Unexposed, developed, fixed, washed</td>
<td>13.7 µ</td>
<td>13.7 µ</td>
</tr>
<tr>
<td>II - D</td>
<td>Unexposed, developed, stop-bath, hardener, fixed, washed</td>
<td>13.7 µ</td>
<td>13.4 µ</td>
</tr>
<tr>
<td>III - A</td>
<td>Unexposed, washed</td>
<td>14.8 µ</td>
<td>15.3 µ</td>
</tr>
<tr>
<td>III - B</td>
<td>Unexposed, washed, hardener</td>
<td>15.1 µ</td>
<td>15.4 µ</td>
</tr>
</tbody>
</table>

Plates in the III series appear to differ in thickness in time. Perhaps slightly different plate was measured on each plate. The error in measurement is about ±0.3 µ.

Juris Ulpienieks, 7 June 1966
7 June 1966

Perhaps because of the relatively large variations in emulsion thickness across the plate, conclusions are difficult to make. It appears that the following statements are true:

1. Exposed, processed emulsion is thicker than unexposed plate by about one third maximum.
2. Fixing shrinks the emulsion 12% to 18%.
3. Emulsion processed with hardener shrinks by about 0.3µ more than one processed without it. This conclusion is supported by observation of back-illuminated holograms.

Due to the many factors affecting the actual optical path length in the emulsion, it seems that conclusions drawn from measurement of light wandering and constructive interference should be more reliable.

Juris Upatnieks, 7 June 1966.

1 August 1966

The analogy of phase-modulated transparency with electrical network.

Phase-modulating a transparency with noise-like signal has several advantages, as discussed previously. The optical imaging system below can be compared to an electrical network.

Juris Upatnieks, 1 August 1966.
The equivalent electrical network would be as follows:

![Diagram of an electrical network]

The signal of a transparency usually consists of a large d.c. term and some high-frequency terms: \( s(x,y) = a_0 + n(x,y) \).

The dispersive network in an optical system is simply free space, and dispersion \( D \) is proportional to spatial frequency content of the signal and the distance \( z \) from the object (or image) plane: \( D \propto Dz \). A may be thought of as being the distance over which the wave front a signal in the transparency is spread out when it encounters noise (but, imperfections in lens or mirror, etc.). Signals of high spatial frequency are dispersed over a large area, and thus for all practical purposes is not affected by defects in the imaging system. In the compression network (focusing), the signal is compressed to focus while the noise is dispersed, thus improving the apparent signal-to-noise ratio. The d.c. term does not get dispersed, and thus is greatly affected by imperfections.

The purpose of the phase-modulation is to disperse the d.c. term \( a_0 \), etc. In this way the \( a_0 \) term is imaged with a smaller effect from defects and the noise is spread out over a larger area, and the interference with the d.c. term produces a slight noise-like background. Finally, if the phase of the transparency is important, then a phase plate with a conjugate phase can be placed at the image plane and thus demodulate the signal.

Juris Upatnieks, 1 August 1966.
Three-dimensional hologram with and without offset frequency.

A hologram was made of the toy train engine without an offset frequency, using this optical system:

The image was reconstructed with a lens as follows:

The d.c. term, and the two bright sideband spots were removed by special filtering. The sideband spots were caused by interference of the reference reflecting off the front surface of the beam splitter and the back surface. The reconstructions were recorded on polaroid film. One image, with large (about 30mm) aperture, was recognizable, but had bright background level of light and consequently poor contrast; another with some aperture but offset to one side, thus effectively having a small offset frequency, was much better. The image with small, 4mm aperture, was very bad without the offset.
5 August 1966.

The four photographs, taken on 29 July 1966, were made under these conditions:

<table>
<thead>
<tr>
<th>Offset Freq</th>
<th>Aperture</th>
<th>Exp. Time</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1 None</td>
<td>30 mm</td>
<td>½ sec.</td>
<td>High background level for image, poor image quality</td>
</tr>
<tr>
<td>#2 Small</td>
<td>25 mm</td>
<td>¾ sec.</td>
<td>Image good, d.c. shows up</td>
</tr>
<tr>
<td>#3 None</td>
<td>4 mm</td>
<td>½ sec.</td>
<td>Image very poor, conjugate image partly in focus and superimposed on in-focus image</td>
</tr>
<tr>
<td>#4 Small</td>
<td>4 mm</td>
<td>¾ sec.</td>
<td>Image good</td>
</tr>
</tbody>
</table>

Conclusion: images without offset frequency are poor even for thin-dimensional diffuse objects.

Juris Apatiņš, 5 August 1966.

5 October 1966 Read and understood by me on Oct 5 1966

Robert Bihlbach

Holograms made with light having short coherence length and limited spatial coherence.

A problem frequently encountered with ordinary coherent light sources is that they have a very limited coherence length and limited spatial coherence. Limited coherence length restricts the number of fringes that one can obtain, and this is very serious with the offset-frequency technique since a fine fringe spacing is required. The source size limits the highest spatial frequency that can be recorded, affects the spatial coherence.

Juris Apatiņš, 5 October 1966
of the light beam, and is also a serious limitation on the offset-frequency technique of holography.

A technique is proposed here that will greatly extend the object (transparency) size of which a hologram can be made with limited partially coherent light, and also improve the resolution of the reconstructed image from such a hologram. A hologram could be made with the optical system shown below.

The light source is assumed to be partially coherent, such as obtained with a mercury-arc lamp with an interference filter and a pinhole. The grating has constant spectral frequency and should have high diffraction efficiency. The two first order sidebands are the filtered out at the transform plane to two partially coherent light sources. The grating, with the d.c. term removed, is imaged and the hologram is made at this plane. The transparency is placed in one beam and a compensating plate in the other. The transparency could be placed anywhere between the transform plane and the hologram plane, just as long as only one beam passes through the transparency.

Since the grating is imaged on the hologram plate, no coherence or monochromacity is required to make the grating, or a hologram of two beams. Some coherence is required.
and monochromaticity is required to record the interference pattern between the light scattered by the object and the reference beam. To estimate coherence requirements, consider the diagram below:

To record light scattered over angle $\phi$ by a point on the object, two requirements must be met. First, the relation

$$\delta z < d_0$$

must hold, where $d_0$ is the coherence length of the light source. For a low-pressure mercury arc lamp, $d_0 \approx 1.2 \, \mu m$, so about 2000 fringes could be recorded. The second requirement that must hold is

$$\frac{a z}{F} < \frac{\lambda}{2\phi}$$

where $F$ is the focal length of the collimating lens, $a$ is the diameter of the pinhole source, and $\lambda$ is the wavelength of light. Also, the lenses must be capable of accurately imaging the grating.

To obtain the greatest area possible for the object, each of the two point sources at the entrance plane should fill half the aperture of the last lens. If lens diameter is $D$, then the frequency of the grating should be

$$f_s = \frac{D}{4\pi (\text{focal length})} = \frac{1}{4\pi (\text{f} \times \text{m} \times \text{m} \times \text{m})}$$
5 October 1966

For a f-5.6 lens system, the grating should have about 70 l/mm, or 100 l/mm for a f-4 system. The useful area for the object will be a circle of about 10 diameter.

This hologram technique has exactly the same requirements on coherence as the solar hologram technique without the offset frequency. The offset frequency present in this system will change the separation of the images, however.

The concept described here was proposed by Emmett N. Keith.

Vojis Čuprík, 5 October 1966

Read and understood by me on Oct 5/1966

B. P. Hildbrand

Read and understood by me on Oct 5/1966, K. A. H陞

11 November 1966

Production of interference fringes with light lacking time coherence.

White light interference fringes were produced with the optical system shown here. A high-pressure mercury arc lamp was used as a light source, focused to a pinhole illuminated by lens L3. No color filters were used. A grating was placed at P, the first two meridians were reflected by a special filter, and the interference pattern was observed to the right of lens L5. The special filter allowed all of the 1st meridian...
11 November 1966

diffracted light to pass through. A microscope was used to observe the fringe pattern at plane $P_1$, image plane of the grating at $P_{11}$, and elsewhere to the right of $L_5$. The following observations were made:

1. With a 50μm pinhole in place, white light interference fringes were observed at plane $P_2$ and everywhere up to the lens $L_5$ where the two beams of light overlapped. There was no separation of colors across the plane of observation anywhere. A slight loss of contrast was observed as one moved away from the plane $P_2$.

2. With the pinhole removed, the effective source size was about 3mm diameter. Good contrast fringes were observed at plane $P_2$ and no shift in color nor loss of contrast was observed over the area of overlapping beams. As the microscope was moved to other planes increasingly further away from $P_2$, the contrast of the fringes decreased.

From the above observations we can conclude that interference fringes can be produced with white light over an area limited only by the aperture of the lens. Furthermore, only special coherence is required to produce fringes at other planes than $P_2$, time coherence is not required.

Jerry Upatnieks, 11 November 1966
Time and spatial coherence requirements for holograms made with optical system shown on pages 47 to 52.

It was mentioned previously that coherence requirements are less severe when for making holograms with the optical system previously described, some calculations are made here.

The two coherent sources are obtained as shown:

Consider collimated white light impinging on the grating having special frequency \( \nu_s \). At \( P_2 \) the spectra of light will be displaced a distance \( x \) from the optical axis, and \( x \) is given by:

\[
x = f \left( \frac{\nu_s}{\lambda_s} \right)
\]

where \( \lambda_s \) is the wavelength of light, at plane \( P_2 \). Distance \( z \) from the two point sources an interference pattern will be formed having spatial frequency \( \nu_s' \):

\[
\nu_s' = \frac{z}{2x} = \frac{z}{2z} \left( \frac{\nu_s}{\lambda_s} \right) = \frac{1}{2} \lambda_s \left( \frac{z}{f} \right)
\]

Since \( \lambda_s \) is independent of wavelength of light, white light fringes will form everywhere in space where the two beams overlap. Thus, time coherence is not required for forming interference fringes on the carrier frequency \( f \). A hologram. It is assumed here that spatial coherence exists at plane \( P_1 \), or that is, light originates from a point source.
16 November 1966.

To calculate the required spatial coherence, consider the following:

\[ d = \text{diameter of pupil} \]
\[ f = \text{focal length of illuminating lens} \]
\[ \lambda_s = \lambda_s \left( \frac{D}{a} \right) \]

We can find coherence at plane \( P_2 \) above from finding spatial frequency at \( P_1 \) that would result from two perfect point sources at each edge of the slit (or pinhole). Thus wavelength \( \lambda_s \), is given by

For example, for \( a = 25 \times 10^{-3} \text{ mm} \) and \( D = 10^{-3} \text{ mm} \), \( \lambda_s = 20 \text{ mm} \).

Fringe visibility (as given in Born & Wolf, p. 267) is the following:

0.9 for \( \frac{1}{4} \lambda_s \)
0.4 for \( \frac{1}{2} \lambda_s \)
0.1 for \( \frac{3}{4} \lambda_s \)

Thus, light waves from two points \( \frac{1}{4} \lambda_s \) apart in plane \( P_1 \) will give fringe visibility 0.9, etc. for other values.

We can calculate the spatial coherence requirement, \( c_2 \), at plane \( P_3 \) (fig. p. 54). At \( P_3 \) the wavefronts are modified by a factor \( \frac{1}{2} \). Then

\[ c_2 = b \left( \frac{1}{2} \right) \text{ for } z = f \]

and this \( c_2 \) is the required spatial coherence at plane \( P_1 \).

If we put a lens after \( P_2 \) and image the grating at plane \( P_3 \), then each point in plane \( P_1 \) interferes with itself, so spatial coherence is required, and \( c_2 = 0 \). Therefore, by imaging a grating, neither time nor spatial coherence is required. Consequently, the carrier frequency can be obtained without any coherence at all.

Juris Upiņevičius, 16 November 1966
Experiments with phase-modulated wavefronts and imaging.

Improved results were obtained with imaging of transparencies illuminated with phase-modulated constant amplitude wavefront. For the purpose of comparison, images illuminated with a plain wavefront and with the differences out-of-focus were also made. The experiments were performed in September 1966, the optical system shown below was used:

![Optical system diagram]

Image with a phase wavefront illumination, with irregular glass removed from the system, 7X19 magnification. This image has high resolution but may appear diffraction patterns on the surface of the lens. Frame is not visible.

Juris Ulpatrickis, 17 November 1966.
Image of the transparency illuminated with phase-undulated wavefront.

The image is gaining at the center, but has grain elsewhere. Due to curvature of lens it was impossible to focus the whole image at once. Moving the film, would bring another area in focus.

Magnification x 14.

Image of the transparency with different (irregular) glass moved 4 cm away from the transparency. The irregular glass acts as a diffuse screen, allowing the transparency to diffuse light being both phase and amplitude variations. The image thus becomes very grainy in appearance.

Juris Upatriek, 17 November 1966
Holohram reconstruction of a transparency illuminated with the same phase-modulated wavefront. Magnification about $x \times 10$. Holohram made as follows:

Reconstructed using this system:

Holohram reconstruction of a transparency illuminated with a phase-modulated wavefront. Magnification about $x \times 10$. Holohram made as follows:

Reconstruction made with this system:

This reconstruction has much better overall quality, indicating that smaller aberrations result from holohrams made with the system shown.

Juris Ustavrevs, 17 Nov. 1966
Technique for obtaining a background scene that appears to be at infinity located at infinity in a hologram.

It may be desirable in a hologram scene to have a background that appears to be at infinity. For example, in a hologram used as a training device, it may be necessary to have a hologram or other objects to have the appearance of being far away. One way to achieve this effect is to first make a hologram of a two-dimensional diffuse surface with the desired scene painted on it. The diffuse surface may be transmitting or reflecting. A hologram would be made of this scene and then reconstructed as a background for a second hologram scene. A possible arrangement is shown here.

All lenses shown here are coherent with each other. Since the background scene was two-dimensional, distortion when it is enlarged should be negligible. The scene is made to appear at infinity by enlarging in the reconstruction process.

J. J. Vivaldi, 18 November 1966

Read and understood
by me on Nov 28/66
B.B. Hildebrand
Read and understood
Nov 29, 1966
P. Jacobson
23 November 1966

Experiments with holograms using partially coherent light sources.

Hologram of the carrier-frequency type were made using a HBO-107 super-pressure mercury arc lamp as a light source. An interference filter was used to select the green line (5461 Å) of the spectrum, and SO-243 film for recording the hologram. The film was developed for 8 min. in Kodak D-19 developer. The following optical system was used:

![Diagram](image)

A special filter at plane $P_2$ selected the 1st order sidebands, and the grating at plane $P_1$ was imaged at plane $P_3$. The objects were transparencies on glass plates with one-half clear. The clear half was inserted in the reference beam to compensate for path differences.

The spatial coherence at $P_1$, using the 2% criterion, is over an area of 13 mm diameter. The hologram at $P_4$ records the object with about 50 l/mm resolution.

The following hologram were made: (on 70 um 50-243 film)

Juris Upatnieks, 23 November 1966
Reconstruction of the above holograms were made using a Spectral Physics 112 laser, in collimated beam of light, wavelength 6328 Å. Reconstructions were recorded on Kodak Panatomic-X film, and thus developed in the standard way. The following optical system was used in reconstruction:

![Optical System Diagram]

Film recordings show (sheet #16, 21 Nov 1966):

#3 Reconstruction from hologram #3, no special filter, exposure times: \(\frac{1}{15}, \frac{1}{8}, \frac{1}{5}, \frac{1}{2}, 1\) sec.

#4 Reconstruction from hologram #1, no special filter, exp. times: \(\frac{1}{20}, \frac{1}{15}, \frac{1}{8}, \frac{1}{5}, \frac{1}{2}, 1\) sec.

Janis Ugarksiks, 23 November 1966
#5  Reconstruction from hologram #4, 5 mm diameter space filter, exp. times: \( \frac{1}{5}, \frac{1}{3}, \frac{1}{3}, \frac{1}{2}, 1, 3 \) sec.

#6  Reconstruction from hologram #4, no special filter, exp. times: \( \frac{1}{5}, \frac{1}{3}, \frac{1}{3}, \frac{1}{2}, 1, 3 \) sec.

(Sheet #17, 21 Nov. 1966):

#1  Reconstruction from hologram #5, with 3 mm diameter special filter, exp. times: \( \frac{1}{5}, \frac{1}{3}, \frac{1}{3}, \frac{1}{2}, 1, 3, 10 \) sec.

#2  Reconstruction from hologram #5, no special filter, exp. times: \( \frac{1}{5}, \frac{1}{3}, \frac{1}{3}, \frac{1}{2}, 1, 3 \) sec.

(Sheet #17, 22 Nov. 1966):

#3  Reconstruction from hologram #2, 7 mm diameter filter, exp. times: \( \frac{1}{50}, \frac{1}{15}, \frac{1}{15}, \frac{1}{9}, \frac{1}{5}, 1 \) sec.

#4  Reconstruction from hologram #3, with 5 mm diameter special filter, exp. times: \( \frac{1}{5}, \frac{1}{3}, \frac{1}{2}, 1, 3 \) sec.

#5  Reconstruction from hologram #1, with 5 mm diameter special filter, exp. times: \( \frac{1}{5}, \frac{1}{3}, \frac{1}{2}, 1, 3 \) sec.

Juris Ulpatieks, 23 November 1966
Other techniques of obtaining carrier frequency with small coherence requirements.

A simplified optical system for obtaining fringes (carrier frequency) for holograms is shown below:

![Optical System Diagram](image)

The second lens can be removed if the diffraction grating is placed a distance greater than \( f \) from lens \( L_2 \). In that case, the image of grating at \( P_3 \) will appear at plane \( P_3 \), distance \( q \) from the lens. Location of \( P_3 \) can be found from the lens formula, and is given by

\[
q = \frac{f^2}{p - f}
\]

Neither spatial nor time coherence is required to obtain the carrier frequency with this system.

The object is placed at \( P_7 \) in one of the two beams, lens \( L_3 \), is not required in this system and can be removed. The spectrum of the grating will then appear to the right of plane \( P_2 \), and the spatial filter would have to be relocated accordingly.

Another technique of obtaining fringes is shown in the diagram on the next page. For this system, some time and spatial coherence is required, but the requirements are small. This system can operate entirely without lenses.
23 November 1966

Mirrors $M_1$ and $M_2$ are parallel to each other, $P_3$ is exactly at the location where the two beams completely overlap, and grating at plane $P_1$ has sufficiently high spatial frequency so that the two 1st order diffracted beams are completely separated from the undiffracted beam and any higher order diffracted beams.

For a given wavelength $\lambda$ of light, a plane $P_3$ exists at which light diffracted from any point in plane $P_2$ coincides with itself. Furthermore, since $P_1$, $P_2$, $M_1$, and $M_2$ form the sides of a parallelogram, the optical path length from any point in $P_1$ to $P_3$ is the same. Since the wave fronts coincide at $P_3$, no special coherence is required.

If the light is not monochromatic, then at plane $P_3$ can be found for only one wavelength $\lambda$, for which no shadow of the wave fronts exists. Thus, for light lacking time coherence, some special coherence must exist at plane $P_2$ in order to form the carrier-frequency at plane $P_3$. The requirements on special coherence are small if the bandwidth of the source is, say, 100 $\text{Hz}$. The lens $L_1$ can be omitted if distance $Z$ is much larger than diameter of $L_1$.

Juris Upatnieks, 23 November 1966
Reconstructions from holograms made with mercury-arc lamp.

Both images below are reconstructions from holograms made on 50-243 Kodak film using super-high-pressure mercury.

Reconstruction from hologram #4, 21 Nov. 66. Print from negative of sheet #16, row #5 (see p. 62). Image is magnified here x3, as compared to the original.

Reconstruction from hologram #3, 18 Nov. 66. Print from negative of sheet #017, row #4, (see p. 62). Image magnified x5, diameters compared to original.

Lamp HBO-107. This arc lamp has coherence length of about 60\lambda in the green line. The experimental optical set-up allowed recording of up to 50\,\lambda/mm resolution for fringe visibility of 0.4. The fine lettering contains some detail in excess of this limit, and thus appears to be lost. Some of the horizontal lines have nearly disappeared. Special filters were used in reconstruction to reduce the noise level in the image. The reconstructions were made with a laser, 6328\,\AA\ wave-length.

J. Upatnick, 2 December 1966
Improved techniques of obtaining carrier frequency with limited coherence.

The optical system on p. 64 has three adjustments which must be made in order to obtain fringes with minimum coherence requirements. These requirements are:
1) Mirrors M₁ and M₂ must be parallel to each other;
2) The grating at P₁ must be perpendicular to M₁ and M₂ and incident light beam parallel to M₁ and M₂;
3) Plane P₃ must be at a location where the two wavefronts overlap and coincide exactly. The first two requirements are severe and must be met very precisely. The third requirement is trivial.

The first requirement, that of having mirrors M₁ and M₂ parallel, can be easily met by using the optical system below:

![Optical System Diagram]

The glass block, of optical grade glass, has sides S₁ and S₂, and sides S₃ and S₄ parallel and optically flat. Thus the alignment of the reflecting surfaces S₁ and S₂ could be done in manufacturing of the glass block, thus simplifying the optical alignment problem. The rotational alignment is the only other critical alignment, and probably could be done by observing fringe contrast at plane P₃ while rotating the glass block.

Juris Ulpādeiks, 14 December 1966
would be placed in one beam only at plane $P_2$, and a material of equal thickness would be placed in the other beam to compensate for differences in path length. The dispersion of different wavelengths of light would be somewhat higher than that for the optical system on p. 64.

Another arrangement which would compensate for dispersion of light is shown below:

For a given ray of light originating at plane $P_1$, distance $x_1$ from the optical axis, the position at plane $P_2$ is $x_2$.

$$x_2 = x_1 + a \cdot \frac{\lambda_s}{\lambda_{s1}}$$

At plane $P_4$, this ray is at $x_4$:

$$x_4 = x_1 + (a+b) \cdot \frac{\lambda_s}{\lambda_{s1}} + b \cdot \frac{\lambda_s}{\lambda_{s2}}$$

$$= x_1 + \lambda_s \left( \frac{a+b}{\lambda_{s1}} - \frac{b}{\lambda_{s2}} \right)$$

Since the quantity $\left( \frac{a+b}{\lambda_{s1}} - \frac{b}{\lambda_{s2}} \right)$ can be made to equal zero by proper choice of parameters, the rays emanating from any point $x_1$ meet at a point $x_4$ and this position is independent of the wavelength of light. Therefore, no coherence is required to obtain the carrier frequency.

Juris Ulpatskis, 14 December 1966
To calculate the spatial frequency at plane $P_4$, consider the ray diagram below:

\[ \sin \alpha = \frac{\lambda_1}{\lambda_{s1}} \]

\[ \sin \alpha + \sin \beta = \frac{\lambda_2}{\lambda_{s2}} \]

\[ \sin \beta = \frac{\lambda_4}{2 \lambda_{s4}} \]

Consider both rays:

\[ \frac{\lambda_1}{\lambda_{s2}} - \frac{\lambda_2}{\lambda_{s1}} = \frac{\lambda_4}{2 \lambda_{s4}} \]

or

\[ f_{s4} = \frac{1}{\lambda_{s4}} = 2 \left( \frac{1}{\lambda_{s2}} - \frac{1}{\lambda_{s1}} \right) \]

Since $f_{s4}$ is independent of the wavelength of light, no time coherence is required to produce interference fringes at plane $P_4$. Therefore, this system will produce a carrier frequency over in white light. The example assumed here assumes identical gratings at plane $P_2$. This assumption is not necessary as white-light fringes can be produced with each of the two gratings at plane $P_2$ with different spatial frequencies and an appropriate choice of plane $P_4$.

James Elgotwick, 14 December 1966
Experiments with bleaching of minoxidial gratings

A number of experiments were conducted with gratings having special frequencies of 50 to 250 l/mm, made by recording the interference pattern of two plane waves. The following bleaching were tried: mercuric chloride, Ferrarno's reducer solution "2" (rubine thaniilolate 16%, water 64%), chromium intensifier Kodak's formula "Bu-4", and Kodak modified Beltrichio reducer formula "R-S-8". The gratings had an average transmission of about 80%, of the above bleachers chromium intensifier was best because of the clear image, without scattered light, that was obtained. Mercuric chloride gave 15% efficiency, but was extremely noisy; chromium intensifier gave efficiencies of up to 25% in each order; the remaining two did not improve diffraction efficiency.

The Kodak "Bu-4" chromium intensifier consisted of the following: water 750 cc, Kodak Potassium dichromate 90 gm, Kodak Hydrochloric Acid C.P. 62 cc, and then water was added to make 1 liter of solution.

Overexposed plates gave better diffraction efficiencies. The following experiment was performed with different exposures:

<table>
<thead>
<tr>
<th>Exposure Time</th>
<th>1st Intensity</th>
<th>2nd Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 sec. (20% trans.)</td>
<td>85%</td>
<td>3% + 3%</td>
</tr>
<tr>
<td>2 sec.</td>
<td>23%</td>
<td>20% + 20%</td>
</tr>
<tr>
<td>5 sec.</td>
<td>21%</td>
<td>24% + 25%</td>
</tr>
<tr>
<td>7 sec.</td>
<td>21%</td>
<td>24% + 26%</td>
</tr>
<tr>
<td>10 sec.</td>
<td>35%</td>
<td>24% + 26%</td>
</tr>
<tr>
<td>15 sec.</td>
<td>26%</td>
<td>23% + 24%</td>
</tr>
</tbody>
</table>

The gratings were recorded on 6x9F emulsion on 4x5½" glass plates. A repetition of the 5 to 10 sec. exposures at a later time gave only 13% efficiency in the 1st order, and the reasons for this change are being investigated.

Juris Upatnieks, 20 December 1966
The bleaching process can be repeated several times to increase diffraction efficiency. A test with gratings having average transmission of 30% was made:

<table>
<thead>
<tr>
<th>1.0</th>
<th>2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>d.c.</td>
<td>d.c.</td>
</tr>
<tr>
<td>1st</td>
<td>2nd</td>
</tr>
</tbody>
</table>

a) Bleached once, processed in water 85% 5%
b) Bleached twice, processed in water 28% 25% 27%
c) Bleached three times, “” “” 15% 20% 18% 17%

Measurements were made with laser light, 6328 Å, and a photomultiplier detector.

Juris Upatnieks, 20 December 1966

19 January 1967

Experiments with holograms made with super-high-pressure mercury arc lamp.

Several holograms were made with the optical system below:

![Hologram Diagram]

With the above system vibration of the steel rail caused poor holograms; occasionally, noticeable alterations at the frequency plane were observed, probably introduced by either the lens or non-uniformity in the grating, or both. The light beam after filters

Juris Upatnieks, 19 January 1967
19 January 1967

in the Fourier transform plane was clean and uniform except for some low-frequency patterns from the diffraction gratings. Holcogams were recorded on 50-243 film, 70 mm wide, and was processed in the standards way. Signal beam was about 2 to 3 times stronger than ref. beam without attenuation. Green interference filter was used.

<table>
<thead>
<tr>
<th>Date</th>
<th>Exp.</th>
<th>Size of source</th>
<th>Exp.</th>
<th>Object</th>
<th>Signal beam</th>
<th>Attenuated?</th>
</tr>
</thead>
<tbody>
<tr>
<td>28 Dec. 1966</td>
<td>50 µ</td>
<td>4 &amp; 10 min.</td>
<td>Fine letters</td>
<td>2 rows</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>28 Dec. 1966</td>
<td>50 µ</td>
<td>2 &amp; 5 min.</td>
<td>Trans. of girl</td>
<td>no</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28 Dec. 1966</td>
<td>50 µ</td>
<td>4 &amp; 10 min.</td>
<td>Green letters</td>
<td>2 rows</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>29 Dec. 1966</td>
<td>25 µ</td>
<td>15 &amp; 30 min.</td>
<td>Fine letters</td>
<td>2 rows</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>29 Dec. 1966</td>
<td>50 µ</td>
<td>2, 4 &amp; 10 min.</td>
<td>Trans. of girl</td>
<td>no</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To avoid vibration and to improve image quality, high-power lenses from P.O.P. processor were used to image the grating and the system was set up on the granite bench. The P.O.P. lenses have 56 cm focal length and on 8 in. aperture.

The following system was used:

[Diagram]

Super-high-pressure mercury arc lamp HBO-107

200 l/sec of 514 nm grating was used, with 1st order diffracted light being about 1/3 to 1/5 as intense as the d.c. term.

Jurič Upatnicki, 19 January 1967
<table>
<thead>
<tr>
<th>Date</th>
<th>Color Plate</th>
<th>Line Width</th>
<th>Exposure</th>
<th>Object Description</th>
<th>Signal Been Attempted?</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 Jan. 1967</td>
<td>50-243</td>
<td>50 µµ</td>
<td>1, 2, 4 min.</td>
<td>Diffuse glass transparency of glass 30 x 30 mm</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>12 Jan. 1967</td>
<td>50-243</td>
<td>50 µµ</td>
<td>2, 8, 10 min.</td>
<td>Diffuse glass</td>
<td>yes</td>
<td>5 min exp, best. Diffraction off appears to be less. Reconstructed system same as with 5 min Exp.</td>
</tr>
<tr>
<td>12 Jan. 1967</td>
<td>50-243</td>
<td>25 µµ</td>
<td>8, 10 min.</td>
<td>Long thin lines, 20 µµ, wide lines</td>
<td>yes</td>
<td>No more detail than for holograms with 50 µµ pinhole. Excellent signal to noise. Last letters have alterations.</td>
</tr>
<tr>
<td>12 Jan. 1967</td>
<td>50-243</td>
<td>25 µµ</td>
<td>8+ 20 min.</td>
<td>Diffuse glass with lines, 13 x 31 cm from hologram</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td>13 Jan. 1967</td>
<td>50-243</td>
<td>50 µµ</td>
<td>9, 10, 20 min.</td>
<td></td>
<td>yes</td>
<td>Good reconstruction, no special signals. &amp; 20 µµ.</td>
</tr>
<tr>
<td>7 Jan. 1967</td>
<td>455° plate, 699F</td>
<td>500 µµ</td>
<td>10, 15 min.</td>
<td>Transparency of glass, 17 x 21 mm, size &amp; dimension</td>
<td>no</td>
<td>Contrast extremely high, #4 plate.</td>
</tr>
<tr>
<td>9 Jan. 1967</td>
<td>455° plate, 699F</td>
<td>500 µµ pinhole</td>
<td>7, 10, 15 min.</td>
<td>Transparency of glass, 17 x 21 mm, size &amp; dimension</td>
<td>no</td>
<td>Plates #5 &amp; 6, almost no image.</td>
</tr>
<tr>
<td>9 Jan. 1967</td>
<td>455° plate, 699F</td>
<td>500 µµ pinhole</td>
<td>20 x 30 min.</td>
<td>Transparency of glass, 17 x 21 mm, size &amp; dimension</td>
<td>no</td>
<td>Plate #5, extremely high contrast.</td>
</tr>
<tr>
<td>10 Jan. 1967</td>
<td>455° plate, 699F</td>
<td>500 µµ pinhole</td>
<td>57 min.</td>
<td>Silicates in plain beam (no diffusen)</td>
<td>no</td>
<td>Plate #8.</td>
</tr>
<tr>
<td>10 Jan. 1967</td>
<td>455° plate, 699F</td>
<td>500 µµ pinhole</td>
<td>10+ 20 min.</td>
<td>Transparency of glass, 17 x 21 mm, size &amp; dimension</td>
<td>yes</td>
<td>Plates #7 &amp; 8, 10 x 10, 20 min. exposure gives best reconstruction.</td>
</tr>
</tbody>
</table>
Holograms on several 9x5 inch glass plates with 649F emulsion were made with the optical system on p. 70.

<table>
<thead>
<tr>
<th>Date</th>
<th>Exposure</th>
<th>F number</th>
<th>Exposure time</th>
<th>Object</th>
<th>Signal beam</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 Jan, 1967</td>
<td>500 μm</td>
<td>10, 20, 30 min</td>
<td>Transparency of girl, 17x21 mm</td>
<td>no</td>
<td>Plates #1 &amp; 2, E = 11x10⁻⁴ on light meter</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>17x21 mm</td>
<td></td>
<td>Contrast very poor</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Poor image quality</td>
</tr>
<tr>
<td>4 Jan, 1967</td>
<td>500 μm</td>
<td>15-20 min</td>
<td>Transparency of girl, 17x21 mm</td>
<td>yes</td>
<td>Plate #3, E = 2x10⁻⁴</td>
<td></td>
</tr>
</tbody>
</table>

(*) indicates this hologram used for making prints of reconstructions

The reconstructions of the 53 μm letters showed considerable aberrations in some parts. It appears that these aberrations are caused either by the imaging lens of the grating, or perhaps the grating itself has aberrations. Otherwise, the reconstructions appear to be of high quality.

It was observed that the contrast of the reconstructed image varied greatly depending on both the signal to reference beam ratio and the exposure density of the hologram (average density). If the signal beam was brighter than reference, then the contrast tended to be very low. If the signal beam was equal to or less than reference beam intensity, then the contrast depended on exposure of the hologram. Underexposed holograms were extremely contrasty. They became less contrasty as the exposure increased, and for highly overexposed holograms the image became negative. These observations were for only for continuous tone holograms illuminated with plane wavefronts.

Jenius Utpatniks, 19 January 1967
Reconstructions with laser from holograms made with super-pressure HBO-107 mercury arc lamp.

IST - 67 - 30

Reconstruction from hologram made on 12 Jan 1967 on 60-243 film 50 µm pinhole, 1 mm exposure. Reconstructed in 6328 Å laser light with filter at the Fourier transform plane of the reconstructed image to reduce scattered light level.

THE BRINGING TOGETHER OF THEORY AND PRACTICE LEADS TO THE MOST FAVORABLE RESULTS. NOT ONLY DOES PRACTICE BENEFIT, BUT SCIENCES THEMSELVES DEVELOP UNDER THE INFLUENCE OF PRACTICE, WHICH REVEALS NEW SUBJECTS FOR INVESTIGATION AND NEW ASPECTS OF FAMILIAR SUBJECTS.

Jurijs Apatručis
26 January 1967
Left: Reconstruction from a hologram made on 12 Jan. 1967 on 35 mm film, stop printed, 5 min. exposure with 589.3 Å Argon laser light. Original size of transparency was 30 X 35 mm, and special filters used in reconstruction with 632.8 Å laser light.

Below:

Reconstructions from one hologram made on 13 Jan. 19 of two figures 22 mm height recorded on 35 mm film, with 589.3 Å Argon laser light. Reconstructions in 632.8 Å laser light. The film was placed at the point (plane) where each figure was to focus.

Juris Ulstārīks
26 January 1967
27 January 1967

A number of reconstructions were made in the original optical system, in which the holograms were made. The major reason was to find out if change in wavelength made any difference in the alterations observed in hologram of the long sentence and having 33 μm wide lines. Also, it seemed necessary to show that good reconstructions could be obtained without a laser. Both the hologram of the long sentence and of the girl were reconstructed with special filter allowing wavelength from orange to green to pass through, and the reconstructed objects appeared to reconstruct white and without any obvious color dispersion. The lack of color dispersion is caused by the fact that the original dispersed reference beam was used and the signal was relatively coarse. The white-light reconstruction was not recorded.

The film recordings show (Sheet #18, 19 Jan. 1967).

#6 Reconstruction of hologram made on 10 Jan. 67 of girl illuminated with plane wavefront: Reconstructed in original reference beam, special filter, 500 μm pinhole


#2 Same as #1, plus -X film.


#3 Reconstruction from hologram of 23 Jan. 67 in original reference beam, 500 μm pinhole, virtual image and +X special filter, Exp.: 5, 10, 20, 40 sec., 1½, 3 min.

#4 Reconstructed from hologram made on 23 Jan. 1967, reconstructed in original reference beam, 400 μm pinhole, virtual wave and.

Exp.: 30, 50, 80, 140 sec.

Juris Ulpiakins, 27 January 1967
27 January 1967

(Sheet #018, 25 Jan. 1967):

#5 Reconstructed from hologram made on 23 Jan. 1967, 250 µm pinhole, in original reference beam, virtual image used, special filter. Exp.: 30, 50, 80, 140 sec.

#6 Same as #5 but 125 µm pinhole used. Exp.: 30, 50, 80, 140 sec. 1, 2, 5 min.

(Sheet #019, 25 Jan. 1967).

#1 Same as #5 above, 125 µm pinhole, Laura slightly tilted, exp. 1, 2, 5 min.

Juris Upatnieks, 27 January 1967

15 February 1967

Experiments with holography using mercury-arc lamp, H BR-107.

Holograms were made with a scatter plate instead of a grating in optical system shown on p. 71. The following holograms were made:

<table>
<thead>
<tr>
<th>Date of exp.</th>
<th>Size of source</th>
<th>Exp. times</th>
<th>Object</th>
<th>Special filter in transform plane:</th>
</tr>
</thead>
<tbody>
<tr>
<td>31 Jan. 1967</td>
<td>250 µm</td>
<td>1, 1½, 2 min. of slit, 30X33 mm.</td>
<td>none</td>
<td>special filter in transform plane:</td>
</tr>
</tbody>
</table>

Only part of the transform reconstructed,

Juris Upatnieks, 15 February 1967
15 February 1967

Date | Size of exp. | Exp. times | Object | Remarks
-----|--------------|------------|--------|---------
2 Feb, 1967 | 250 μ | 1, 1½, 2 min. | Transparency of 30 x 30 mm in 10 cm | Filter in transform plane

Only part of the spectral spectrum at the transform plane reconstructed.

2 Feb, 1967 | 250 μ | 1, 1½ | Same as above, but | Same filter as above, transform plane

object in transform plane

Jenius Upatnicks, 15 February 1967

16 February 1967

Experiments with holograms made using mercury-vapour lamp 150 - 107.

Exposure | Source | Film | Exposure | Remarks
---------|-------|------|----------|---------
23 Jan, 1967 | 500 μ | plate, 1400F | 20 min. or 30 min. | Holограм made with 108 lenses, a 200 l/min grating, with the big aperture as the object. Plate #11. Object in 1st oder, no attenuator used.

A number of reconstructions were made from various holograms that are of significant importance.

Jenius Upatnicks, 16 February 1967
<table>
<thead>
<tr>
<th>Negative #</th>
<th>Date made</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>24 Jan. 1967</td>
<td>Reconstructed from hologram made on 23 Jan. 1967 with laser light. Image has better overall appearance, although lines are not as sharp.</td>
</tr>
<tr>
<td>#3</td>
<td>6 Feb. 1967</td>
<td>Fourier transform of the same hologram from which #2 was made.</td>
</tr>
<tr>
<td>#5</td>
<td>6 Feb. 1967</td>
<td>Same as #4, but image magnified.</td>
</tr>
</tbody>
</table>

Juris Ulpatiņš, 8 March 1967
Holosgrams made with ruby pulse laser

Holosgrams were made with Optics Technology pulse laser model 130, having 6943 Å wavelength output with maximum of 5 joules/pulse energy. Near infrared laser energy meter MI-2, series no. 33, was used to measure the output energy of the laser. The optical system shown below was used to make holo
grams:

- 45 in. focal length
- 12 in. focal length
- B1
- B2
- B3
- 

Focal plane of gazing or water plate. Holosgram recorded here.

Note: optical axis of input beam from L1 to L2 offset so as to make the zero order and one 1st order diffraction by a 200 l/mm gazing central on the optical axis of lenses L3 and L4.

The holograms were recorded on either 649F emulsion or 4×5×½ in. glass plates or on 70 mm wide 50-243 film. The output of the laser was measured for each pulse as there was no consistency between input and output energy of the pulse, so a trigger was used. Some exposures on 649F emulsion were obtained by multiple exposures. It was found that the speed of the Polaroid 55 P/N film was about the same sensitivity as the 649F emulsion. The 50-243 is extremely sensitive and required considerably attenuation even at minimum energy output from the laser, of about 0.1 joules.

Juris Alpatiches, 8 March 1967.
8 March 1967

The object for all of the following holograms was a 21 x 17 mm wide transparency of the girl.

<table>
<thead>
<tr>
<th>Date</th>
<th>Exposure</th>
<th>Attenuator</th>
</tr>
</thead>
<tbody>
<tr>
<td>17 Feb, 1967</td>
<td>0.15 to 0.6</td>
<td>22% trans.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>in ref. -29 mm</td>
</tr>
</tbody>
</table>

Plate #12, all underexposed. 4.6 joule exposure has lower density. (4.6 joule output from 2 x 2500 J input).

Plate #13, several good exposures, diffuser before transparency. 200 l/mm grating, transparency 17 mm from hologram. Reconstruction extremely good.

20 Feb, 1967 | 0.19 to 3.6 | 22% T (-29 mm) |

Plate #14, correct exposure. 0.19 joules + 200 l/mm grating. Object 47 mm from hologram, no diffuser. Clear reconstruction, good, but has some fringe patterns that make appearance very poor.

23 Feb, 1967 | 0.015 to 1.27 | Home -296 mm |

Plate #15. Diffuser in d.c. order, no object. Reconstruction shows that special frequencies of up to 10 l/mm are recorded. This indicates lower loss from special coherence.

27 Feb, 1967 | 0.7 to Home | 150 mm |

Plate #16. Wide angle diffuser in d.c. order, transparency, 200 l/mm grating. Reconstruction extremely poor, grainy, with scattered bright spots.

1 March 1967 | Exp. 0.2 | Home |

Plate #17. Transparency in Fourier transform plane. Scatter plate instead of grating. Reconstruction not sharp.

Junes Alpatievski, 8 March 1967.
8 March 1967

Date of exp. Exposure Attenuator Remarks

1 March 1967 0.2 to 4.3 joules None -180 mm Plate #18. Lightly multiple exposures with plate shifted between exposures. Poor reconstructions, scatter plate.

1 March 1967 0.2 to 4.3 joules None -276 mm Plate #19. Scatter plate instead of grating. Object transparency 17 cm from hologram. Reconstruction good.

2 March 1967 1.5 to 8 joules None -276 mm Plate #20. Scatter plate object in Fourier transform plane. Reconstruction acceptable, has some fringes across.

With the scatter plate, the following special filter arrangement was used:

Good images (reconstructions) can be made with the scatter plate and the object in either the transform plane or near the hologram. Spectrum over the whole filter aperture was recorded and the problems encountered with the Hg-arc were not evident. With the Hg-arc lamp only a small part of the special spectrum could be recorded at a time. Even pulse laser has excellent coherence, so spread due to lack of monochromaticity is encountered. The image is degraded by lack of spatial coherence only. It is interesting to

Jurus Eppetticks, 8 March 1967.
8 March 1967

Note that granularity is dependent only on the aperture at the transform plane and not by the spatial coherence of the source. The resolution is directly related to its spatial coherence. Thus, granularity and resolution are independent of each other with a scatter plate arrangement. With a grating as the beam splitter, resolution and granularity both are directly related to the spatial coherence.

Several holograms were made on 50-243 film.

<table>
<thead>
<tr>
<th>Date of exp.</th>
<th>Exposure</th>
<th>Attenuator</th>
<th>FoV</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 Feb. 1967</td>
<td>0.04 to 0.24</td>
<td>3% T</td>
<td>-35 mm</td>
<td>Hologram of transparency 17 cm from hologram, 200 l/mm grating, vs diffuser. Reconstruction poor, image had in intense fringe patterns.</td>
</tr>
<tr>
<td>6 March 1967</td>
<td>0.11 to 0.68</td>
<td>5%</td>
<td>-35 mm</td>
<td>Scatter plate, transparency in Fourier transform plane, some spatial filter as on p. 83. Reconstruction good but less true resolution. Scatter plate.</td>
</tr>
<tr>
<td>#1</td>
<td>jules</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td>jules</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 March 1967</td>
<td>0.24 to 1.23</td>
<td>3%</td>
<td>-35 mm</td>
<td>Scatter plate, object transparency 17 cm from hologram, some spatial filter as on p. 83. Reconstruction excellent; small grain and very good resolution.</td>
</tr>
<tr>
<td>#3</td>
<td>jules</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td>jules</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 March 1967</td>
<td>0.015 to 0.45</td>
<td>3%</td>
<td>-35 mm</td>
<td>200 l/mm grating, low angle scatter plate 1 cm from object transparency 15 cm from hologram. Reconstruction good, a little grainy.</td>
</tr>
</tbody>
</table>

Juriis Uspatrevics, 8 March 1967
10 March 1967

Pulse laser holograms.

A pulse laser is known to have excellent time coherence and poor spatial coherence. For the optical system on p. 81, with $k_1 = -20\,2\%$, the apparent source size was calculated to be about 500 $\mu$ diameter. Good holograms can be made with it using the imaged grating or scatter plate technique, but the aperture is severely limited by the aperture of the lens. The objects are limited to those that can be viewed in transmission or in silhouette.

In order to examine possibilities of obtaining larger apertures and perhaps going to 3-dimensional objects, the following optical system was set up:

For alignment, a ground glass screen with ground fine wires was placed at $P_3$ and imaged to plane $P_3$. The mirrors were adjusted so that sharp images were formed at plane $P_3$ and the images coincided from both patterns. The ground glass screen with the ground mirrors was then removed from the system.

Read undated on March 14, 1967

Jimmers Upstakiers, 10 March 1967
10 March 1967

With the face irregular glass plate moving, CW laser, and the system adjusted properly, stationary light contrast fringes were observed at plane P1. The fringes were visible with a source 50 cm diameter that was monochromatic and specifically incoherent. Fringes could be observed across the whole field, about 12 cm in width, and about 1 cm out of focus either direction from plane P3. Stationary fringes at input plane P3 could be seen with the ground glass in place at plane P1. The fringes had some appearance when the moving irregular glass screen was removed from the beam.

With the system adjusted as before and the ground glass removed from plane P3, an irregular glass was placed at plane P3 (this glass scatters light over a limited angle, about +5° from ZC). Some fringes could be seen, but they appeared in spots only and had low contrast. These fringes were stationary. As the irregular glass was moved toward plane P3, the contrast of these fringes increased and they could be seen over a larger area. The irregular glass was inserted in one beam only. This observation indicates that some coherence is maintained through irregular glass. With a smaller specially incoherent source, the fringes should become more arbitrary and should be visible over a larger area.

The observations that fringes were present with specially incoherent light over a depth of 4 cm, and through irregular glass, indicates that this technique could be extended to diffusely reflecting or transmitting objects and to three-dimensional diffusely reflecting objects. Calculations indicate that a depth of 525 cm could be achieved, and coherence area of the beam of 70 cm diameter should be possible.

Richard understood on March 14, 1967
Jim Upatnick, 10 March 1967

R. Mitchell

Read & understood on March 14, 1967
A. A. Everett
10 March 1967

Holograms were made with the optical system as shown, L₁ = 35 mm, Optics Technology pulse laser model 130, at 69.43 A, n = 1. The object transparency was at P₁, with irregular glass plate 10 mm behind it, and P₂ about 45 cm from P₃. 50-243 film was used, and viewing glass was removed from the front of L₁.

The following exposure were made, with numbers in parentheses indicating input energy to laser: 0.23 jule (1225 jule), 0.12 (1100), 0.42 (1400), 0.85 (1600), 1.22 (1800), 1.90 (2020), 1.70 (2250), 1.90 (2500), 3.2 (2 x 2500).

The transparency was then removed, mirror M₂ was replaced by a toy train, and the following exposure were made (reference beam was not attenuated): 0.26 jule (1225 jule), 0.13 (1225), 0.32 (1400), 0.74 (1600), 1.20 (1800), 1.50 (2000), 1.50 (2250), 2.10 (2500), 3.8 (2 x 2500).

Juvis Upatniets, 10 March 1967

Read and understood on March 14, 1967
B.B. Heldbrand

Read and understood on March 14, 1967
A.Q. Fiese

14 March 1967

Cubic laser holograms.

The hologram above of the transparency gave a reasonably good reconstruction. The image was weighted, or was of nonuniform brightness with maximum brightness at the center and decreasing brightness in all directions from the center. This change in brightness might have been caused by rotational misalignment of the prism-type drum splotter. The imaged pattern of two crossed wires on ground glass appeared to be rotated with respect to each other from the two paths, such a misalignment would cause reduction.

Juvis Upatniets, 14 March 1967
of fringe contrast as one moved in a radial direction away from the point of coincidence of the two images. With better alignment this difficulty could be avoided. The 0.12 joule exposure was the best, slightly too dark.

The other hologram of the toy train did not reconstruct any image. The cause may be the extremely high reference beam relative to the signal beam, and the poor spatial coherence since the train was far away from the hologram and close to the beam splitter.

Holograms were made with the same optical system as shown on p. 85 except L3 was replaced by a 50 mm f/1 lens. Exposures ranging from 0.1 to 3.9 joules were made with the irregular glass as a diffuser, and 30 x 33 mm size transparency as the object. Another set of exposures were made with sand blasted glass as the diffuser and the same object. The shorter focal length of L3 in the optical system should increase spatial coherence by a factor of 3 and decrease intensity by a factor of 9. Images through both paths were carefully adjusted to make them coincide.

Juris Upatnicks, 14 March 1967

22 March 1967

Experiments with pulse laser holograms

Good reconstructions were made from the holograms above made on 14 March 1967. The best exposures were in the range 0.5 to 0.7 joules. When the virtual image was observed, the whole transparency could be seen from any part of the hologram. This indicates that

Juris Upatnicks, 22 March 1967
spatial and time coherence was maintained between every point of the reference beam and the object (transparency). The reconstructions are very clear with fine detail visible. Small granularities across the image are evident. These are caused from the irregular pattern in the beam illuminating the diffuser, and the diffuser being so close to the transparency, about 1 em. With this system, it should be possible to make holograms of 3-dimensional objects. The reconstructions were made on 17 March 1967 and were recorded on Polaroid type 55 P/N film.

The 50-229 film was tested for sensitivity at 6328 A with a light meter reading of \( 1.9 \times 10^{-3} \) 25 sec. exposure, and neutral density wedge step with 60% transmission, exposure density of about 20% was achieved. This indicates that 50-229 is about 6 times faster than F 0.95 on glass plates. 50-229 was developed for 6 min in D-19.

Janice Opatrni, 22 March 1967

4 April 1967

Experiments with pulse laser holograms.

A pulse laser hologram was made with the following optical system of a three-dimensional object:

The distances are the same as for the optical system on p. 85. The hologram was made on 2 March 1967. Exposures: 2.16 pulses (3-pulses), 4.5 pulses (8-pulses), 6.3 pulses (13 pulses).

Janice Opatrni, 4 April 1967
4 April 1967

The 4 pulse exposure was the last one. Reconstruction were made on 3 April 1967, and were rather noisy. Only the central part of the train was reconstructed and the signal to noise ratio was low. However, a three-dimensional object was photographed and reconstructed. Apparently sufficient spatial coherence is maintained only at the center of the object field, several pulses are required to obtain sufficient exposure which sometimes cause interference effects at the object or on the film. It appears that the spatial coherence must be improved without the loss of energy to make good three-dimensional holograms.

Juris Upatnieks, 4 April 1967

20 April 1967

Spacial coherence of ruby pulse laser; Optronics Technology Model 130.

A number of experiments have been performed during the last month to determine if the spatial coherence of the pulse laser could be improved. The poor spatial coherence is the result of the high gain of the ruby laser and the short resonant cavity. Many modes besides the ones on the optical axis are supported by the laser, resulting in wide divergence of the output beam. The coherence was measured by making a hologram of a diffuse glass and then measuring the bandwidth of spatial frequencies recorded on the hologram. The bandwidth is determined by illuminating the hologram with a collimated beam of laser light and looking at the Fourier transform spectrum by means of a lens.

Juris Upatnieks, 20 April 1967
With the laser cavity in its original arrangement, the divergence of the beam was measured to be 0.0017 radians or about 0.1°; with the cavity extended from its original length of 33 cm to 118 cm, the divergence was measured to be 0.06° or 0.001 radians. With a 300 mm focal length lens, this corresponds to 500 μm diameter light source in the first case, and 300 μm diameter light source in the second. To obtain good holograms of three-dimensional object, the source size should be about 1μm, or a few wavelengths in diameter. It should be noted that the coherence measurements are of questionable accuracy due to difficulties in performing the experiments.

Apparently, spatial coherence is improved by increasing cavity length and there is no loss in output power. Improvement in coherence can be expected since the modes would have to be closer to the axis of the cavity to reflect back and forth between the mirrors. Assuming that equivalent source size decreases by some ratio as increase in cavity length, more than 33 meter cavity length would be required to get a 50μm diameter source or 165 meter for a 1μm source. It cannot be expected that this relation remains true for very long cavity lengths, since diffraction effects and density variations in air become important.

In general, the problem of transverse mode selection is illustrated by the following diagram:

![Diagram of laser setup]  

In order for laser action to take place, a wavefront must be reflected back and forth through the ruby.

Juris Uspatnieks, 20 April 1967
in such a way that gain exceeds losses until a maximum value is reached. Assuming a perfect cavity with perfect alignment, the rays parallel to the optical axis satisfy the above condition. Rays at small angles may travel through the cavity several times until they begin to hit the restricting apertures of the cavity and are attenuated.

Using this simple model, transverse modes should be reduced under the following conditions:

1) The length of the cavity is increased. An off-axis ray can travel fewer times through the cavity. Experimentally, there seems to be no decrease in output energy with increasing cavity length, but there is improvement in spatial coherence.

2) Restrict the aperture of the cavity. Reason for improvement is same as in (1). Interspace measurements show not linear mode, but energy output measurements are the following:

<table>
<thead>
<tr>
<th>Output energy</th>
<th>Input energy</th>
<th>Shape of aperture</th>
<th>Ratio of original power to power with aperture</th>
<th>Ratio of original to restricted aperture</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.2 joules</td>
<td>2500 joules</td>
<td>none ($\frac{3}{5}$)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1.9 joules</td>
<td></td>
<td>$\bigodot$ $\frac{11}{12}$</td>
<td>1.16</td>
<td>1.19</td>
</tr>
<tr>
<td>0.7 joules</td>
<td></td>
<td>$\bigodot$ $\frac{7}{12}$</td>
<td>3.1</td>
<td>2.9</td>
</tr>
</tbody>
</table>

3) Place a unity telescope in the cavity and use special filtering. The special filter should restrict the wavefronts in essentially one direction. Very good lenses with low reflection and extremely precise alignment would be required.

A simple experiment with inexpensive single-lens lenses purchased from Edmund Scientific was conducted with the following results:

Juris Upatnīks, 20 April 1967
20 April 1967

<table>
<thead>
<tr>
<th>Output energy</th>
<th>Input energy</th>
<th>Laser, if any</th>
<th>Pinhole, if any</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9 joules</td>
<td>1600 joules</td>
<td>none</td>
<td>none</td>
</tr>
<tr>
<td>0.3 &quot;&quot;</td>
<td>1600 &quot;&quot;</td>
<td>Two 156 mm</td>
<td>none</td>
</tr>
<tr>
<td>0.07 joules</td>
<td>1600 joules</td>
<td>none</td>
<td>0.31 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pinhole approximated, much larger than focus of 156 mm lens</td>
<td></td>
</tr>
</tbody>
</table>

It seems that a unity telescope would offer the best possibility of achieving good spatial coherence without excessive loss in output energy. This scheme depends on the quality of components and execution of alignment which might be difficult to achieve. Even if everything was perfect, the relay itself has considerable non-uniformity (±) in transmission according to Abbé's formula which would make it impossible to pass a given wavefront many times through the same pinhole as it traverses the cavity. A ± change in optical path length across the ruling is very severe as compared to the standards of optical flats or interferometers.

Juris Ulpatricks, 20 April 1967

22 June 1967

Experiments with reducing spatial frequencies in holograms

Experiments were made to test the ideas described on pp. 140 - 145 in notebook 768, dated 21 Oct. 1965. Since the technique visualizes the use of restricting apertures, the first experiments were designed to test the appearance of images through these apertures without reducing spatial frequencies. The experimental system is shown.

Juris Ulpatricks, 22 June 1967
22 June 1967

below.

![Diagram of optics setup]

- Granite block surrounded by infinite inner tubes

- Holoscreen H2 made from hologram H1

The real image of hologram H1, one was reconstructed behind the viewer position where hologram H2 would be made. Due to lack of proper lenses, it was not possible to reconstruct H2 at one-to-one scale, and the real image was somewhat magnified. Apertures of various sizes were placed directly in front of H1. The reference beam was introduced as shown in order to facilitate reconstruction of hologram H2, since one singly has to illuminate H1 with a diverging beam of light. For the hologram where the aperture was a single rectangular bar, H2 was changed so that the laser beam was concentrated in this aperture. The reconstructed image was quite bright in the latter case.

Juris Upatnieks, 22 June 1967
22 June 1967

Hologram H1 was adjusted while the reconstructed real image was observed with a magnifier. The hologram could be adjusted so that the real image appeared quite sharp and well resolved.

The following holograms were made from a 4.55-in.

### Aperture | Light intensity | Exposure | Comments
--- | --- | --- | ---
| 1-1/4" | 30 x 10^-9 | 70 to 120 sec. | Correctly exposed. Hologram reconstructed a very neat and bright image. It could be easily seen in 1/4 of phase with a 1 mm beam aperture 100 cm away. (Hologram made on 17 Feb 67.)
| 1-2 1/3" | 14 x 10^-4 | 75 to 85 sec. | Exposure somewhat dark. Reconstruction good, and good paralax visible in upward-downward direction, (exp. made 15 Feb 67.)
| 1-1/4" | 7 x 10^-3 | 20 and 30 sec. | Due to the small aperture the signal was very small, but high enough over the hologram. H2, H3, H4, latter signal the reference ratio must be large. No linear reconstruction. (Exp. made on 15 June 67.)

Juris Ulipāraks, 22 June 1967
22 June 1967

The holograms were reconstructed as follows:

\[ \text{Real image of source} \]

\[ \text{Restricting aperture} \]

When the eye was placed at the position of the real image of the aperture, the whole scene could be seen at once. At other places only part of the scene could be seen at one time.

Juris Upatnieks, 22 June 1967

22 June 1967

Efficient single-sideband diffraction from two-dimensional gratings.

Blochéed gratings of photographic plates are known to diffract more light into a sideband that one, having intensity variations only. Such gratings tend to diffract a large portion in both 1st orders, 2nd orders, etc. One way to restrict the diffraction to only one sideband is to mask the gratings in three-dimensional recording medium. Another technique is described here to achieve the same result with a two-dimensional recording medium.

Consider the diffraction by a plane grating on the next page. The conditions for diffraction in the \( b_2^+ \) direction are that the condition

\[ d (\sin \beta_i + \sin \beta_{2^+}) = \lambda \]

are satisfied.

Juris Upatnieks, 22 June 1967
22 June 1967

For the diffraction in \( \beta_{-n} \) direction, the conditions are

\[
d \left( \sin \beta_{-n} - \sin \beta_i \right) = 0
\]

It is possible choose the parameters \( \beta_i, \beta_{n+} \) and \( d \)

such that equation (1) will be satisfied and equation (2)

cannot be satisfied. The conditions for 2nd order

diffraction in the \( \beta_{n+} \) direction are

\[
d \left( \sin \beta_i + \sin \beta_{n+} \right) = 2d
\]

and in general for higher order diffractions in the \( \beta_i \)

direction the relationship is

\[
d \left( \sin \beta_i + \sin \beta_{n+} \right)^n = n \cdot d, \quad n = 0, 1, 2, ...
\]

By proper selection of \( \beta_i \) and \( d \) it is possible that

eq. (4) is satisfied only for \( n = 0 \) and \( n = 1 \). Diffraction

in the zero order direction can be eliminated by proper

phasing of the grating. The light energy then must be either

diffracted into the +1 order or be reflected. It appears that

the light energy would go mostly in the +1 order,

possibly with a 90\% efficiency.

As a special case, consider \( \beta_i = \beta_{n+} \) and then

\[
d \sin \beta_i = 0
\]

To eliminate -1 order the relation

\[
d \left( 1 - \sin \beta_i \right) \geq 0
\]

or

\[
\sin \beta_i \leq 1 - \frac{d}{2}
\]
must be satisfied. From eq. (5) and (7) we find that

\[ d \leq \frac{3}{2} \lambda \]  \hspace{1cm} (8)

or

\[ \beta_i \geq 20^\circ \]

For this choice of \( \beta_i \) and \( d \) the \(-1\) and higher negative orders are also suppressed.

Such blanked (or phased) gratings and Ewald zone plates could be useful as high-efficiency optical elements.

Juris Upratikis, 22 June 1967

11 August 1967

Production of phase plates having random phase distribution.

The image quality of transparencies and similar objects can be improved if they are illuminated with a constant-amplitude, random-phase wavefront. Such wavefronts are produced by passing a plane wavefront through transparent material one side of which is irregular. Such an irregular surface can be made by recording an interference pattern and blanching it.

One desirable quality of an irregular random phase plate is that it contains equal amounts of energy in all spatial frequencies used. Another one is that the pattern is random, which can be easily achieved by recording interference pattern from a ground glass screen.

Juris Upratikis, 11 August 1967
First, the energy content of an interference pattern from a diffuse surface will be calculated, consider the case below:

In the screen distance $z$ from diffuse glass plate interference pattern is formed having spatial frequency $f \approx \frac{k}{z}$. At (b) we consider the area of small strips $dx$ wide and separated by $b$ and assume that only points parallel to $x$-axis interfere to produce a frequency component in that direction. Furthermore, assume that energy is proportional to the number of $dx$'s over a distance $b$ apart. Energy can then be calculated to be

$$E \propto \int_0^b a \, dx = ax \bigg|_0^b = ab$$

A plot of this for a function of $b$ is shown at right:

A similar calculation can be made for a circular aperture:

$$h_1(x) = \sqrt{r^2 - x^2} = r \sqrt{1 - \left(\frac{x}{r}\right)^2}$$

$$E \propto 4 \int_{b/2}^r h_1(x) \, dx = 4 \int_{b/2}^r \sqrt{r^2 - x^2} \, dx$$

$$= 2\left[ x \sqrt{r^2 - x^2} + r^2 \sin^{-1}\left(\frac{x}{r}\right) \right]_{b/2}^r$$

$$E = k \pi r^2 \left[ \pi - \sqrt{1 - \left(\frac{b}{r}\right)^2} - 2 \sin^{-1}\left(\frac{b}{2r}\right) \right]$$

James Elphick, 11 August 1967
The plot for the circular case is very similar to the rectangular case (in one dimension) except that the curve is not exactly a straight line. These two calculations show that recording an interference pattern at an out-of-focus plane will not give a uniform spatial frequency content in the interference pattern. A better technique is to image the diffuse surface and place a spatial filter in the transform plane. In this case the spatial frequency content of the interference pattern should be uniform (equal energy for all frequencies) since a diffuse surface has such distribution before filtering. The diagram below shows the optical system:

With this system any desired frequency range could be obtained by adjusting the aperture. The bleaching process is non-linear and thus will generate higher spatial frequencies than passed by the aperture. The result should be better, however, than by recording patterns at an out-of-focus plane.

Juris Ulpatricks, 11 August 1967
Experiments with production of phase-modulator plates by bleaching.

Phase-modulator plates were made by recording wave-pattern from a diffuser illuminated with coherent light. The pattern was recorded on 6 x 9 in. glass plates. The optical system used to make the wave pattern was the following:

The pass-band of the spatial filter for the 305 micron focal length lenses was calculated to be the following:

<table>
<thead>
<tr>
<th>Lines/m(\mu)</th>
<th>Aperture diam.</th>
<th>Lines/m(\mu)</th>
<th>Aperture diam</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>3.05 mm</td>
<td>80</td>
<td>15.3 mm</td>
</tr>
<tr>
<td>25</td>
<td>4.8</td>
<td>100</td>
<td>19.0</td>
</tr>
<tr>
<td>40</td>
<td>7.6</td>
<td>160</td>
<td>30.5</td>
</tr>
<tr>
<td>60</td>
<td>11.5</td>
<td>200</td>
<td>3.8</td>
</tr>
</tbody>
</table>

The following plates were exposed:

<table>
<thead>
<tr>
<th>Plate #</th>
<th>Spatial freq of aperture</th>
<th>Density</th>
<th>Transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25 8/(\mu)</td>
<td>1.3</td>
<td>6%</td>
</tr>
<tr>
<td></td>
<td>50 8/(\mu)</td>
<td>2.2</td>
<td>0.7%</td>
</tr>
<tr>
<td>2</td>
<td>25 8/(\mu)</td>
<td>1.3</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>50 8/(\mu)</td>
<td>2.2</td>
<td>0.7%</td>
</tr>
<tr>
<td>3</td>
<td>75 8/(\mu)</td>
<td>2.2</td>
<td>0.7%</td>
</tr>
<tr>
<td></td>
<td>100 8/(\mu)</td>
<td>2.2</td>
<td>0.7%</td>
</tr>
<tr>
<td>4</td>
<td>75 8/(\mu)</td>
<td>2.0</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td>100 8/(\mu)</td>
<td>2.0</td>
<td>1%</td>
</tr>
</tbody>
</table>

Juris Upatrics, 22 August 1967
<table>
<thead>
<tr>
<th>Plate #</th>
<th>Spatial freq. (c/m)</th>
<th>Density</th>
<th>Transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>25.0 c/m on both</td>
<td>2.6 and 3.8</td>
<td>0.26% and 0.16%</td>
</tr>
<tr>
<td>6</td>
<td>25.0 c/m on both</td>
<td>&quot;</td>
<td>0.26% and 0.016%</td>
</tr>
</tbody>
</table>

All plates were developed in D-19 for 5 min, and fixed.

Two bleaches were used to convert intensity variations into thickness variations and to remove the silver grain. One was Kodak Chromate-10 bleach sold in packets with a bleach and a clearing bath. The other bleach was the Kodak R-10 bleach.

Although the chemical composition of the Chromate Intensifier is not known, it appears similar to that described in the photographic index and the results seem to be similar to that. The formula for Chromium Intensifier given in the index is the following:

Water 750.0 cc
Kodak Potassium Dichromate 900 gms
Kodak Hydrochloric Acid, C.P. 64.0 cc
Add water to make 1.0 liters

The formulas for Kodak R-10 bleach are as follows:

**Solution A**
- Distilled water 500 ml
- Ammonium Dichromate 20 gms
- Concentrated Sulfamic Acid 14 ml
- Distilled water to make 1.0 liters

**Solution B**
- Sodium Chloride 45 gms
- Distilled Water to make 1.0 liters

For use, mix one part sol. A, one part sol. B, and 10 parts of water.

Juris Upleivicks, 22 August 1967
Plates #1 and #2 were bleached in the Chromate intensifier in the following manner: the plate was placed in Chromate bleach until the image disappeared, for about 3 min; it was then washed and placed in a clearing bath, washed again, and then fixed and washed. Plate #1 was bleached three times, with developer being added after the first two bleachings, and fixed after the last one.

Plate #5 was bleached in Kodak R-10 as follows: washed 10 min, bleached for about 3 min, until cleared; washed for 4 min, fixed 8 min, washed for 15 min or more, photo-flushed and dried.

When viewed under a microscope with a 4 mm f.1 lens, all of the above plates appeared to have major intensity fields, with lower magnification some irregularities appeared. The spectrum of the plates appear about 4 or 5 times broader than that recorded, also, when slightly defocused the pattern has low spatial frequency which increases as defocusing is increased. The plates appear to have too high a frequency content for most applications. The problem apparently is that the layers of the irregularities are too steep. Better plates should have finer high-frequency irregularities.

One way to improve the results might be to place a spatial filter with rippled gratings. This should reduce low-frequency components.

James Upatnick, 22 Aug. 1967
August 24, 1967

Experiments with producing high-efficiency diffraction gratings by bleaching recorded interference patterns.

A number of gratings were made by recording the interference patterns of two beams of light on 649 F emulsion supported by 4x5 x 1/8 in. glass plates. The plates were then bleached and diffraction efficiency was measured. The optical system used to make the plates is shown below.

![Optical System Diagram]

The gratings were then bleached in various bleaches. Some of the bleaches used had the following chemical content:

1. Mercuro Chloride bleach:
   a) Kodak Potassium Bromide 22.5 gms
   b) Mercuro Chloride 22.5 gms
   c) Water to make 1.0 liters

This solution loses potency with time and has undesirable side effects, such as coloring. The bleach used was rather old so fresh solution might give better results.

James Upatnieks, 24 August 1967
August 24, 1967

2. **Kodak Intensifier, Kodal To-4**
   a) Water 750.0 cc
   b) Kodal Potassium Bromide 90.0 gms
   c) Hydrochloric Acid, C.P. 64.0 cc
   d) Add water to make 1000 cc

3. **Kodak Bleach Bath R-10**
   Sol. A
   a) Distilled water 500 ml
   b) Ammonium Bichromate 20 gms
   c) Concentrated sulfuric acid 14 ml
   d) Distilled water to make 1000 cc

   Sol. B
   a) Sodium chloride 45 gms
   b) Distilled water 1000 cc


The test results (measurement of efficiency of diffraction) are the following:

<table>
<thead>
<tr>
<th>Material</th>
<th>Max. % off</th>
<th>Transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury chloride bleach, dry plate</td>
<td>50%</td>
<td>97%</td>
</tr>
<tr>
<td>Chromate bleach, dry plate</td>
<td>25%</td>
<td>91%</td>
</tr>
<tr>
<td>Chromate bleach, wet plate</td>
<td>9%</td>
<td>64%</td>
</tr>
<tr>
<td>Kodal R-10 bleach bath, dry plate</td>
<td>41%</td>
<td>57%</td>
</tr>
<tr>
<td>Kodal R-10 bleach bath, wet plate</td>
<td>49%</td>
<td>47%</td>
</tr>
</tbody>
</table>

*These readings may be somewhat high due to unknown water usage.

In all of the cases above the plates were not finished after bleaching. If the plates are fixed after bleaching, the transmission increases to nearly that of clean glass but the diffraction efficiency falls to a few percent or less than one percent. The major disadvantage of omitting the fixing is that the emulsion remains somewhat dark and absorb less light. The color is usually yellowish or brownish. In one of the chromate bleach, the commercially available Chromium intensifier

James Upatridge, 24 August 1967
was used and it contained a clearing bath. The clearing bath turned the brownish color into a slightly white deposit throughout the emulsion, without affecting the efficiency of diffraction. The average transmission was slightly better with the clearing bath; the chemical composition of the clearing bath is not known. It was observed that the wet emulsions were unstable and turned darker with time.

Another fact appears from the measured efficiencies that diffraction efficiency is dependent on the thickness of the emulsion. By keeping the emulsion unit (it was wetted and covered with clear glass) the thickness can be increased by a factor of three. By controlling the quality of the water and by avoiding use of a hardener, this increase could be as high as 10\% (from Table 4 in the book The Theory of Photographic Process). The last column on the previous page suggests that any further increase would be small since usually less than 14\% is transmitted through the plate at the angle of diffraction. A rather large increase should be possible if the absorption of the emulsion can be decreased without lowering the index of refraction change within the emulsion.

Of the losses, 10\% occur of reflection at the 1st surface of the glass. If all the light was diffusedt without absorption, then an efficiency of 80\% could be achieved. By coating the surfaces a still further improvement should be possible. In the above experiments, the \( E \) is parallel to the plane of incidence and the angle between the two beams was \( 90^\circ \).

The experimental work was done Carl Leonhard.

Juris Upatriks, 24 August 1967
20 September 1967

Experiments with bleaching of recorded interference patterns.

Experiments and investigations of the bleaching patch reactions was continued. Spatial emphasis was placed on the investigation of the chemical reactions that take place during bleaching process.

The probable chemical reactions of the chromate bleaches are probably the following:

Kodak K-10 bleach without NaCl

\[
6 \text{Ag} + (\text{NH}_4)_2 \text{Cr}_2 \text{O}_7 + 7\text{H}_2\text{SO}_4 = 3 \text{Ag}_2 \text{SO}_4 + \text{Cr}_2(\text{SO}_4)_3 \downarrow + (\text{NH}_4)_2 \text{SO}_4
\]

not. probably not.

with NaCl the reaction might be

\[
6 \text{Ag} + 6\text{NaCl} + (\text{NH}_4)_2 \text{Cr}_2 \text{O}_7 + 7\text{H}_2\text{SO}_4 = 6 \text{AgCl} \downarrow + \text{Cr}_2(\text{SO}_4)_3 \downarrow + 3\text{Na}_2 \text{SO}_4 + (\text{NH}_4)_2 \text{SO}_4
\]

n = 2.07 inmol. probably sol. vol.

Kodak K-9 bleach

\[
6 \text{Ag} + K_2 \text{Cr}_2 \text{O}_7 + 7\text{H}_2\text{SO}_4 = 3 \text{Ag}_2 \text{SO}_4 + \text{Cr}_2(\text{SO}_4)_3 \downarrow + K_2 \text{SO}_4 + 7\text{H}_2\text{O}
\]

Kodak Tr-4 chromium bleach

\[
\text{Ag} + K_2 \text{Cr}_2 \text{O}_7 + 14\text{HCl} = 8\text{AgCl} \downarrow + 2\text{Cl}_2 \text{O}_3 \downarrow + K\text{Cl} + 7\text{H}_2\text{O}
\]

invol. invol. sol.

Another chromate bleach variation

\[
6 \text{Ag} + (\text{NH}_4)_2 \text{Cr}_2 \text{O}_7 + 14\text{HCl} = 6\text{AgCl} \downarrow + 2\text{Cl}_2 \text{O}_3 \downarrow + 2(\text{NH}_4)\text{Cl} + 7\text{H}_2\text{O}
\]

invol. invol. sol.

Juris Ulpatrieks, 20 Sept. 1967
20 Sept. 1967

The packaged Kodak chromium intensifier states that it contains \( \text{KCrO}_3 \) as the bleaching agent. If we assume that \( \text{H}_2\text{SO}_4 \) is used as the acid, then the reaction should be:

\[
6\text{Ag} + 2\text{KCrO}_3 \text{Cl} + 6\text{H}_2\text{SO}_4 \Rightarrow 2\text{AgCl} \downarrow + \text{Cr}_2(\text{SO}_4)_3 \downarrow + \text{K}_2\text{SO}_4
\]

\[
+3\text{H}_2\text{O} \uparrow + 2\text{Ag}_2\text{SO}_4 \text{vol.}
\]

The chemicals probably include some other compounds which react with \( \text{SO}_4^2- \) and remove it. The question of what is contained in the clearing bath is not known. It is possible that the yellowish color is caused by some residual sulfur compound and that the clearing bath reacts with it or dissolves it from the solution. The clearing bath does not change the efficiency appreciably and tends to leave a whitish residue.

In the above reactions the index of refraction is apparently caused by the following compounds remaining in the emulsion:

<table>
<thead>
<tr>
<th>Compound</th>
<th>Index of Refraction</th>
<th>Color in Crystalline Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{Cr}_2(\text{SO}_4)_3 )</td>
<td>?</td>
<td>violet or red</td>
</tr>
<tr>
<td>( \text{AgCl} )</td>
<td>2.071</td>
<td>white</td>
</tr>
<tr>
<td>( \text{CrCl}_3 )</td>
<td>?</td>
<td>violet</td>
</tr>
</tbody>
</table>

The above bleach baths are all used as intensifiers. Intensification is achieved by developing the bleached plates causing the following reaction:

\[
\text{AgCl} + \text{Cr}_2(\text{SO}_4)_3 + \text{developer} \Rightarrow \text{Ag} + \text{Cr} + \text{other sol. comp.}
\]

Besides the original silver, chromate is also deposited in the emulsion.

Juris Upatnieks, 20 Sept. 1967
21 Sept. 1967

Other chemical compounds for bleaching photographic plates.

The following reactions may take place and increase the index of refraction. The reactions with a (V) have been tried and bleaching action was observed:

1. \( \text{Ag} + 3\text{H}_2\text{O} + \text{KI} + \text{K}_3\text{Fe(CN)}_6 = \text{AgI} \downarrow + \text{K}_4\text{Fe(CN)}_6 \cdot 3\text{H}_2\text{O} \)

2. \( \text{Ag} + 3\text{H}_2\text{O} + \text{KBr} + \text{K}_3\text{Fe(CN)}_6 = \text{AgBr} \downarrow + \text{K}_4\text{Fe(CN)}_6 \cdot 3\text{H}_2\text{O} \) (V)

3. \( \text{Ag} + 3\text{H}_2\text{O} + \text{KCl} + \text{K}_3\text{Fe(CN)}_6 = \text{AgCl} \downarrow + \text{K}_4\text{Fe(CN)}_6 \cdot 3\text{H}_2\text{O} \)

4. \( \text{CuBr}_2 + \text{Ag} + \text{H}_2\text{O}_2 = \begin{cases} \text{AgBr} \downarrow + \text{CuO} \downarrow + \text{H}_2\text{O} & \text{(V)} \\ \text{AgBr} \downarrow + \text{Cu}_2\text{O} \downarrow + \text{H}_2\text{O} & \text{light brown} \end{cases} \)

5. \( \text{CuBr}_2 + \text{Ag} + \text{H}_2\text{O} = \begin{cases} \text{AgBr} \downarrow + \text{Cu} \downarrow \\ \text{AgBr} \downarrow + \text{CuBr} \\ \text{AgBr} \downarrow + \text{Cu}_2\text{O} \downarrow + \text{Cu(OH)}_2 \downarrow \\ \text{light pink} \end{cases} \) (V)

6. \( \text{Ag} + 4\text{K}_3\text{Fe(CN)}_6 = 3\text{K}_4\text{Fe(CN)}_6 + \text{Ag}_4\text{Fe(CN)}_6 \downarrow \) (V)

7. a) \( \text{Ag} + \text{K}_2\text{Cr}_2\text{O}_7 + 14\text{HCl} = 6\text{AgCl} \downarrow + 2\text{KCl} + 2\text{CrCl}_3 + 7\text{H}_2\text{O} \)

b) \( 2\text{AgCl} + 2\text{CrCl}_3 + \text{NaOH} = 8\text{NaCl} + \text{Cr}_2\text{O}_3 \downarrow + \text{H}_2\text{O} + \text{Ag}_2\text{O} \)

or \( 2\text{AgCl} + 2\text{CrCl}_3 + 8\text{NH}_4\text{OH} = 8\text{NH}_4\text{Cl} + \text{Cr}_2\text{O}_3 \downarrow + 8\text{H}_2\text{O} + \text{Ag}_2\text{O} \)

In order for the bleaching action to take place with the desired increase in index of refraction, two conditions must be met by the bleach: the chemical reaction takes place only in presence of silver and

Juris Vjatnieks, 21 Sept. 1967
and one of the products (or more than one) must be insoluble and have higher index of refraction than the emulsion. These conditions are met by all of the above equations. The color of the crystal refers to its bulk form, not dispersed in fine form in the emulsion, and it may have different appearance in fine suspended state. The following table lists the optical properties of the deposited compounds as given by the Handbook of Chemistry and Physics:

<table>
<thead>
<tr>
<th>Compound</th>
<th>Index of Refraction</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag I</td>
<td>2.21</td>
<td>yellow</td>
</tr>
<tr>
<td>Ag Br</td>
<td>2.253</td>
<td>pale yellow</td>
</tr>
<tr>
<td>Ag Cl</td>
<td>2.071</td>
<td>white</td>
</tr>
<tr>
<td>Cu O</td>
<td>2.63</td>
<td>black</td>
</tr>
<tr>
<td>Cu O₂</td>
<td>2.705</td>
<td>red</td>
</tr>
<tr>
<td>Cu Br</td>
<td>2.116</td>
<td>white</td>
</tr>
<tr>
<td>Cu(OH)₂</td>
<td>?</td>
<td>blue</td>
</tr>
<tr>
<td>Ag₂ Fe(CN)₆</td>
<td>?</td>
<td>white</td>
</tr>
<tr>
<td>Cu Cl₃</td>
<td>?</td>
<td>violet</td>
</tr>
<tr>
<td>Cu O₂</td>
<td>2.551</td>
<td>green</td>
</tr>
<tr>
<td>Ag₂ O</td>
<td>?</td>
<td>brown-black</td>
</tr>
<tr>
<td>Ag₂ O₂</td>
<td>?</td>
<td>grey-black</td>
</tr>
</tbody>
</table>

Other compounds having high index of refraction are listed below:

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th></th>
<th>n</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hg I₂</td>
<td>2.75, 2.75</td>
<td>Al Cl₃</td>
<td>2.7</td>
<td>(2.100 μm)</td>
</tr>
<tr>
<td>Sn S</td>
<td>2.11</td>
<td>Sn I₃</td>
<td>2.78</td>
<td></td>
</tr>
<tr>
<td>Tl Cl</td>
<td>2.25</td>
<td>Ba O</td>
<td>1.98</td>
<td></td>
</tr>
<tr>
<td>Pb I</td>
<td>2.78</td>
<td>Ba S</td>
<td>2.16</td>
<td></td>
</tr>
<tr>
<td>Cu I₄</td>
<td>2.006</td>
<td>Ud O</td>
<td>2.49</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cu S</td>
<td>2.137</td>
<td></td>
</tr>
</tbody>
</table>

Juris Uphieks, 21 September 1967
26 September 1967

Effect of phase-modulated wavefront on the appearance of the image.

One use of a phase-modulated wavefront would be to illuminate essentially two-dimensional microscopic specimens. Since phase-modulation of the image increases the spatial bandwidth of the object, either better optical systems must be used or else some degradation in the image quality can be expected.

If the signal is $s(x,y)$ and the phase wavefront is $\phi(x,y)$, then the resulting spectrum is $S*V$, where the capital letters the Fourier transforms of the inputs $s$ and $\phi$. If $\delta$ is near the diffraction limited bandwidth of the optical system, then $S*V$ is likely to exceed this limit. For the case where $s(x,y)$ is well imaged by itself, some interesting results may be obtained when $S*V$ is present. For example, if $s(x,y)$ is a pure phase object, then $s(x,y)\phi(x,y)$ may give intensity variations where the product exceeds the bandwidth.

Since $s(x,y)$ is pure phase and is random in character, the intensity variations also will be random. If the inputs are of the form $s(x,y) = e^{i \omega(x,y)}$ and $\phi(x,y) = e^{i \beta(x,y)}$, then intensity variations should exist whenever

$$\frac{\partial^2 \phi(x,y)}{\partial x \partial y} + \frac{\partial^2 \phi(x,y)}{\partial y \partial y} \approx k \omega \text{ max}$$

where $\omega \text{ max}$ is the bandwidth of the optical system and $k$ is the appropriate constant. By varying the aperture at the transform plane or $\omega$ may be varied. Alternatively, $s(x,y)$ or additional random phase may be introduced in the reconstruction process, varying with time perhaps, and thus high lines of high spatial frequency content may be converted into intensity varying lines at the image plane.

Jerius Upatnick, Sept. 26, 1967
Improvement of the brightness of multiple image holograms.

The idea of superimposing several holograms on the same plate is well known and has been demonstrated experimentally. The exposures are usually made so that the total exposure of the plate is same as for a single hologram. For example, if object intensity is I and T is time required to reach optimum density of the hologram, then assuming all objects to have same intensity, the exposure for each hologram would be I/T. Consequently, the brightness of each image is approximately T as compared to a single exposure.

The brightness of each superimposed hologram can be increased by the following method: an exposure level is experimentally found which would give approximately linear, noise-free reconstruction when bleached (density changed into index of refraction change). Experiments have shown that such bleached hologram has approximately the same diffraction efficiency as an optimum unbleached hologram. The multiple-image hologram is then made by exposing the film for the same time as for a single-image hologram. Thus, the total exposure is IT/N or N times the normal exposure. Since after bleaching all density is changed into index-of-refraction changes, no light is lost due to absorption by the density of the exposed film. Furthermore, the index-of-refraction changes for each individual hologram remains the same provided that linear portion of the NIT curve is not exceeded. For the 649F emulsion a density of 3 to 4 can easily be reached and it should be possible to place several holograms on one plate without decreasing the brightness of each.

Jarius U. Patikas, 17 October 1967
Holograms of three-dimensional objects with light sources having limited spatial coherence.

If holograms are made with light sources having poor spatial coherence, the hologram reconstructions are rather poor due to a large blur building. This is illustrated in the figure below.

If the reference beam has coherence over an area having diameter "a" and if the object has coherence over area of diameter "b", then light arriving from area "b" will be recorded over hologram area "a" and the rest of the light, being incoherent, will simply raise the uniform blur level of the hologram and consequently decrease the signal-to-noise ratio. The net result is that only part of the object can be seen from any point of the hologram.

The incoherent light can be eliminated from the hologram by inserting a restricting aperture between the object and the hologram recording plate, as shown here:
By positioning the mask as shown in the figure, only three rays incoherent with the reference beam are obstructed and the coherent rays are allowed to reach the photographic plate. It is assumed here that the reference beam is positioned in such a way that the rays passing through the aperture meet from a given point on the object and meet with a corresponding part of the reference beam which is coherent with that point. No light energy is lost by this technique and an improved signal-to-noise ratio will result.

Frequently the energy available to expose the hologram from a spatially coherent source is too low to expose a high-resolution photographic emulsion. This may require the use of higher speed film with lower resolution. If the reference beam is positioned so that it appears to come from a point close to the aperture of the mask, then the spatial frequencies can be made arbitrarily low choosing the proper mask-to-hologram distance. Also, the signal-to-noise ratio can be easily increased by several orders of magnitude using this technique since the mask in the reconstruction step will remove most of the scattered light from the object plane. If one desires to view the virtual image and see the whole scene of one at a second hologram can be made from this one in a manner described earlier.

Juris Upatnicks, 18 October 1967

Read and understood by me  O. Friesen  Oct 20, 1967
25 October 1967

Holograms made through restricting aperture.

The characteristics of holograms made with a restricting aperture in front of it has been described before. A relaxation of spatial coherence requirements can be achieved if a focusing element is placed at the aperture. Consider the figure below:

With the aperture alone, light from a pt A on the object passes through aperture and falls on an area and on the hologram. If a partially coherent light source is used (good time coherence but poor spatial coherence), the reference beam may manipulated that the area a-a' is illuminated by reference beam coherent with the light falling on pt A. We may think of the aperture acting as a pinhole lens. The area a-a' can be reduced to a very small size by placing a lens at the aperture so that the image is approximately focused on the photographic plate. By this means, the light source could have much lower spatial coherence.

To cover an object of considerable depth, the illuminated area ideally should come from the center of the aperture. Under these conditions, the light coming from pt A will always be coherent with reference beam at pt A' no matter how far the object is from the

Juris Uzatavics, 25 October 1967
25 October 1967

Aperture. This is illustrated below:

From the figure it is evident that no matter how far the object is from the lens, the part of the object illuminated by the coherent section of illuminating beam will always reach the same part of the photographic film. Thus, an excellent match between reference and signal beams is always possible. Although the illuminating beam comes from a virtual source point in the lens, in practice an approximation may be sufficient, that of placing the point source to one side, near the aperture. The second hologram would be made by reconstructing hologram H₁ through the same lens. By this technique the effect of the lens is, would be completely removed and one could see the whole image at once from the position of the lens aperture. All the aberrations introduced by the lens will also be removed.

If we have a highly coherent light source, then a random phase plate may be placed in the aperture. By this means the object can be encoded in making hologram H₁ and decoded in making hologram H₂.

Experiments with phase-modulated wavefront illumination in microscopy.

Some experiments were performed to determine the quality of images one can obtain with coherent light and phase-modulated wavefront illumination. The following optical system was used:

The following exposures were made:

<table>
<thead>
<tr>
<th>Negative #</th>
<th>Focal length of objective</th>
<th>Distance D</th>
<th>Plate - modulator</th>
<th>Date exp. made</th>
<th>Exposure Time</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8 mm</td>
<td>65 cm</td>
<td>Plate #10, 8.5 nA</td>
<td>28 Oct. 67</td>
<td>1 sec</td>
<td>Obj. polystyrene, exposure</td>
</tr>
<tr>
<td>2</td>
<td>8 mm</td>
<td>65 cm</td>
<td>Plate #10, 8.5 nA</td>
<td>&quot;</td>
<td>7/10 sec</td>
<td>&quot;</td>
</tr>
<tr>
<td>3</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>1/5 sec</td>
<td>&quot;</td>
</tr>
<tr>
<td>4</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>1/2 sec</td>
<td>&quot;</td>
</tr>
<tr>
<td>5</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>1 sec</td>
<td>&quot;</td>
</tr>
<tr>
<td>6</td>
<td>4 mm</td>
<td>&quot;</td>
<td>Plate #1, 15 cm</td>
<td>&quot;</td>
<td>2 sec</td>
<td>&quot;</td>
</tr>
<tr>
<td>7</td>
<td>&quot;</td>
<td>&quot;</td>
<td>Plate #10, 8.5 nA</td>
<td>&quot;</td>
<td>2 sec</td>
<td>&quot;</td>
</tr>
<tr>
<td>8</td>
<td>8 mm</td>
<td>&quot;</td>
<td>Plate #10, 8.5 nA</td>
<td>&quot;</td>
<td>2 sec</td>
<td>exp. o.k.</td>
</tr>
<tr>
<td>9</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>2 sec</td>
<td>&quot;</td>
</tr>
<tr>
<td>10</td>
<td>&quot;</td>
<td>&quot;</td>
<td>Plate #11, 16 cm</td>
<td>&quot;</td>
<td>5/2 sec</td>
<td>exp. o.k.</td>
</tr>
<tr>
<td>11</td>
<td>8 mm</td>
<td>65 cm</td>
<td>Triangular fiber</td>
<td>30 Oct. 1967</td>
<td>3 sec</td>
<td>no object or 100 mm lens</td>
</tr>
<tr>
<td>12</td>
<td>4 mm</td>
<td>&quot;</td>
<td>&quot;</td>
<td>30 Oct. 1967</td>
<td>5 sec</td>
<td>&quot;</td>
</tr>
<tr>
<td>13</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>14</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>15</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
</tr>
</tbody>
</table>

(1) For these exposures the 100 mm lens was removed and plan plate was moved to object position. This was done also for photographs 1-5 made on 30 Oct. 1967.

Juris Upatnieks, 30 October 1967
31 October 1967

Imaging through a microscope:

Exposure made 28 Oct. '67, #2

Magnification: X 80
Objective: 8 mm f.d., N.A. = 0.50
Phase-modulated wavefront illumination.

Exposure made 28 Oct. '67, #4

Magnification: X 80
Objective: 8 mm f.d., N.A. = 0.50
Plan wavefront illumination.

Exposure made 28 Oct. '67, #5

Magnification: X 80
Objective: 8 mm f.d., N.A. = 0.50
Diffuse wavefront illumination.

Juris Upatnicks, 31 October 1967
The pictures with plane wavefront illumination show that the noise level is quite bright. The plane-modulation converts this noise into random pattern, but it is still quite apparent and distracting.

Exposure made 28 October 1967, #6
Magnification: x160
Objective: 4 mm f/2, N.A. = 0.65
Plane wavefront illumination.

Note that the ring structure below appears as an irregular intensity pattern here. The object is no longer completely masked in places by ring patterns.

Exposure made 28 Oct. 1967, #7
Magnification: x160
Objective: 4 mm f/2, N.A. = 0.65
Plane wavefront illumination.

The concentric rings are probably from glass-air surface reflections.

Juris Zipsatriekis, 31 October 1967
Exposure made on 30 October 1967, #2

Magnification: X160
Objective: 4 mm f.1., N.A. = 0.65
Plane wavefront illumination

Exposure made on 30 October 1967, #3

Magnification: X160
Objective: 4 mm f.1., N.A. = 0.65
Plane wavefront illumination

Exposure made on 30 October 1967, #4

Magnification: X160
Objective: 4 mm f.1., N.A. = 0.65
Bi-pleura illumination wavefront

Juris Upatnieks, 30 October 1967
Reduction of noise level due to scattered light by use of partially coherent light.

The microscopic images on the previous pages show that the noise level is rather high due to various optical elements in the imaging system. The use of plane-parallel wavefront breaks the noise into random pattern, but the level remains just as high. Some improvement in signal-to-noise ratio could be achieved by the use of partially coherent light if two conditions are satisfied: 1) the image is nearly in focus, and 2) the imaging system (lenses) can be considered to be space invariant, that is, they have the ideal properties of a perfect lens. If these properties are satisfied, then a light source with partial spatial coherence could be used and the techniques of superimposing corresponding parts of the same wavefront at the hologram plane could be employed. Since the light, both in signal and reference beams, would be coherent over only a small area, then light scattered by defects of the imaging system would be incoherent with other areas except area $dA$. Thus, if the noise is scattered over a large area compared to $dA$, considerable reduction in noise level would be possible.

An optical system as shown below could be used for this purpose:

![Optical system diagram](diagram)

The optical system would be carefully adjusted so that corresponding parts of the wavefront would match exactly at the hologram plane. Object $O$ would be positioned to come to focus at plane $H$. Coherence of moving waveplate would determine degree of spatial coherence. Because of decreased coherence, this system would be affected less by noise in lenses and other parts. A phase-modulated tilt could be used behind the object.

June 1967
21 November 1967

removing of intermodulation terms in a hologram electronically (by filtering in time domain).

If a hologram pattern is to be read off by a scanning device, such as a photomultiplier tube or a TV-image pickup tube, then it could be advantageous to use two light frequencies that are slightly different. The resulting a.c. signal could be filtered and separated from the intermodulation terms usually present in a hologram, and the bandwidth requirement could be reduced by one-half. Consider the signals

\[ m_0 = a_0 \cos(x \pm j \omega_1 t) \quad \text{reference signal} \]

\[ m = a(x, y) \cos[(\phi(x, y) - \omega_2 t)] \quad \text{information-bearing signal} \]

The intensity of this signal is then proportional to

\[ <(m_0 + m)^2> = \frac{1}{2} a_0^2 + \frac{1}{2} a^2(x, y) \]

\[ + <a_0 a(x, y) \cos[\phi(x, y) - \omega_1 x + (\omega_2 - \omega_1) t]> \]

Before averaging, the other coefficients had frequencies of approximately \(2\omega_1\) associated with them except the cross product that has \((\omega_2 - \omega_1)\) frequency and this would be quite low (under 100 MHz). If the difference frequency is exact, then a narrow-band a.c. amplifier can be used to pick up the \(a \cos(\phi(x, y), \omega_1 t)\) term and separate it from the rest. This signal thus could be eventually recorded on film, for example, and a constant bias term could be added. This system would have several advantages: 1) A bias term could be introduced which could be constant and therefore independent of \(a(x, y)\), and, since narrow-band amplifiers tend to be relatively noise-free, the relative values of \(a_0\) and \(a(x, y)\) would not greatly affect the image quality; 2) \& since the intermodulation terms

Juris Upatnieks, 21 November 1967
terms are removed from the cross-product term, the spatial carrier frequency could be reduced by one-half thus decreasing the required bandwidth for transmission of the hologram signal; 3) since the difference frequency for many lasers is of the order 80 - 200 MHz, the signal could be directly amplified for transmission and thus simplify required electronic circuitry.

Ideally the object should be illuminated with light waves having frequency \( \omega_1 \) and the reference signal should have frequency \( \omega_2 \), such that the difference \( (\omega_1 - \omega_2) \) is approximately constant. This might be difficult to achieve in practice, but fortunately lasers ordinarily have several axial modes where difference frequencies are repeated by multiples of \( (\omega_1 - \omega_2) \), where \( \omega_i \) and \( \omega_j \) are two adjacent modes. The sum of all the adjacent difference frequencies then could be used as the \( (\omega_1 - \omega_2) \) frequency. These locking may be required, but that can be easily achieved in practice.

Some arbitrary difference frequency could be generated by modulating one of the beams or disturbing the path to generate a doppler shift in frequencies. Juris Upatnieks, 21 November 1967.

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29 November 1967

Corrections and comments on the above idea.

The difference frequencies between axial modes would not separate \( \alpha_2 \) and \( \alpha_{(x,y)} \) terms from the desired signal if some axial modes are present in both reference and signal beams, since \( \alpha_2 \) and \( \alpha_{(x,y)} \) would contain the same difference frequencies. If a laser is operating in, say, two transverse modes, then those transverse modes can be operated by spatial filtering and one mode could be used for a reference and the other for illuminating the object. The difference frequencies between transverse and axial modes generally are not the same.

Juris Upatnieks, 29 November 1967
Recovery of high-quality images from holograms made with half-plane filtering.

A technique for making and reconstructing holograms using half-plane filtering was described by Kohlrausch [Optica Acta (Paris) 3, 87 (1956)] and was described from communications theory point of view later [Keith and Upatnickis, J. Opt. Soc. Am. 52, 1128 (1962)].

The hologram obtained was described in the later paper as:

\[ XX^* = s_x^2 + s_y (s_x f^2 g^2) + s_y (s_x f^2 g^2)^* + |s_y f^2 g^2|^2 \]

A high-quality image can be recovered from each hologram if spatial filtering is used with a lens half, which is positive and half of which is a negative lens. This type of filtering operation was described a paper "Requirements for Hologram Construction", Keith, Kogura, and Upatnickis, Proceedings - Spring Joint Computer Conference, 1966, in connection with a hologram produced in a different way. The optical system was as follows, but now we place a half-

\[ \text{Plane filter hologram at the input which is described by the equation above. The symbols above mean the following:} \]

- \( s_x \) = bias or d.c. term of the signal
- \( s_x \) = the a.c. part of signal
- \( f \) = dispersion function
- \( g = \frac{1}{2} \hat{s}(x) + \frac{i}{\pi x} \) = Hilbert transform of a half-plane filter

Janis Upatnickis, 11 January 1968
11 January 1968

The 2nd and 3rd terms in the first equation contain one half of the spatial frequency spectrum of the signal. By proper choice of the basis \( b \) we can multiply each of the spectrum in the reconstruction process \( f^* \) and \( f \), and we get the mixed signal \( s \) which is

\[
s_i = s_b^2 + s_b (\pi_i f^* g) + s_b (\pi_i f^* f^*) + \ldots
\]

\[
= s_b^2 + s_b (\pi_i g) f^* f^* + s_b (\pi_i g)^* f^* f^* + \ldots
\]

\[
= s_b^2 + s_b (\pi_i g) + s_b (\pi_i g)^* + \ldots
\]

Substituting \( g = \frac{1}{2} \delta(x) + \frac{\pi_i}{\pi} x \), we get

\[
s_i = s_b^2 + s_b s_b^* (\frac{1}{2} \delta(x) + \frac{\pi_i}{\pi} x) + s_b s_b^* (\frac{1}{2} \delta(x) - \frac{\pi_i}{\pi} x) + \ldots
\]

\[
= s_b^2 + s_b (3 \pi_i + \pi_i^*) + s_b (\pi_i - \pi_i^*) + \ldots
\]

If \( s_b \) is a real signal, then

\[
|s_i| = s_b^2 + s_b s_b^* + \text{intermodulation terms}
\]

Thus we have recovered the signal as though the complete spectrum of the signal was recorded, and yet we have eliminated the conjugate image term. Above \( s_b \) is a constant and therefore not important. The recovered image with half-plane filtering in both construction and reconstruction contained the term \(-\frac{1}{2} s_b s_b^* (\frac{\pi_i}{\pi} x)\) which was quite annoying. In this case it is completely eliminated. The noise term \( \pi_i f^* g \) could be made small by increasing the noise term.

It should be noted that the elimination of the extraneous term occurs only if the input signal \( s_b \) is real.

Janis Upatnieks, 11 January 1968
Recording and reconstruction of plane object using positive-negative lens in transform plane.

In the paper "Requirements for Hologram Reconstruction", Proc. Spring Joint Computer Conf. 1966, describes a technique of making holograms with this optical system:

The question will be considered here as to what is reconstructed if the input signal is complex, that is, if it is a plane object.

The effect of the filter on the signal at the hologram plane can be described by

\[ f \ast g + f^\ast g^\ast \]

where \( f \) is \( \exp(ik(x^2 + y^2)) \) is the dispersion factor, \( g \) is the half-plane filter.

In the reconstruction process the lens in filter plane is reversed and the action of the filter can be described by

\[ f \ast g^\ast + f^\ast g \]

The * indicates conjugate and \( \ast \) indicates convolution.

Juris Upatnieks, 18 January 1968
Some of the properties of the Hilbert transform, and of function \( f \), are listed here:

\[
\begin{align*}
g \ast g &= g \\
g \ast g^* &= 0 \\
g^* \ast g &= g^*
\end{align*}
\]

Let the signal be \( s = s_b + s_n \), where \( s_b \) is the average transmitted term, the d.c. term, and \( s_n \) is the ac. signal, a complex number. At the hologram plane we get a signal \( \mathbf{X} \) which is

\[
\mathbf{X} = s_b + s_n \ast f \ast g + s_n \ast (f \ast g)^*
\]

(3)

The film records

\[
\mathbf{X} \mathbf{X}^* = s_b^2 + s_b (s_n \ast f \ast g) + s_b (-s_n \ast f^* \ast g^*) + s_b (s_n \ast f \ast g)^* + |s_n \ast f \ast g|^2 + |s_n \ast f \ast g|^2
\]

(4)

The recorded hologram signal is reconstructed through the filter expressed by eq (2), and using above Hilbert transform relations and filter relations, we get

\[
\mathbf{X} \mathbf{X}^* [f \ast g^* + f^* \ast g] = s_b^2 + s_b s_n \ast g + s_b s_n \ast g^* + s_b s_n \ast \text{intermodulation terms}
\]

(5)

\[
= s_b^2 + s_b s_n \ast(g + g^*) + s_b s_n \ast (g^* + g) + \text{intermodulation terms}
\]

\[
= s_b^2 + s_b s_n + s_b s_n \ast \text{intermodulation terms}
\]

since \( g + g^* = \mathbf{6}(x) \)

\[
= s_b^2 + s_b \text{Re} s_n + \text{intermodulation terms}
\]

The hologram reconstructs the real part of the original signal.
1 February 1968

Imaging with Fresnel lens made by recording interference pattern between two beams and bleaching it.

Zone plates were made with the optical system below:

The recorded interference pattern was then bleached in modified R-10 bleach to improve diffraction efficiency, and then it was used to image a transparency consisting of transparent background letters on opaque background. The transparency was illuminated with incoherent (spatially) laser light obtained by moving a diffusing screen in the laser beam. To obtain the conjugate of one beam for best resolution, a lens was used to image the transparency 101 cm in front of the hologram, as shown below:

Janis Uptauw Jr.
1 February 1968
Image with a single zone plate, made on 18 December 1967. 40 mm aperture, focal length ~30 cm, f-2, 4 sec exposure. Half-power points are approximately ±2.5° from the center. Note that aberrations increase quickly in directions away from least focus.

This image is same as above but with a 10 mm aperture, or f-32, exposure made on 18 December 1968.

Juris Upatnieks
1 February 1968.
Image with a double zone plate, having 2½° separation between them. Exposure made on 4 January 1968, aperture 10 mm, focal length ~11.5 cm, f-81, exposure time 100 sec. The two areas at which each zone plate gives a sharp image is clearly visible.

Image with some double zone plate as above, made on 4 January 1968. Exposure was 15 min., aperture 3 mm, aperture f-35. Note that image is good over the whole field of view, thus demonstrating that improved imaging can be obtained with multiple zone plates.

Juris Ulpatiņš
1 February 1968
1 February 1968

Calculation of the distance at which a periodic structure repeats, or "focuss" by itself.

Consider the diagram below:

\[
\sin \theta_n = n \frac{\lambda}{d_0} = n \lambda f_0 = \frac{d_2 - d_1}{\lambda} \approx \frac{d_2}{\lambda}
\]

where \( n = 0, 1, 2, \ldots \)
\( \lambda \) is the wavelength of light, and \( d_0 \) is spatial period.

We must find \( z \) such that \( d_2 - d_1 = N \lambda \), where \( N = 0, 1, 2, 3, \ldots \)

\[
\sin \phi = \frac{d_2}{d_2 + z} \quad \text{and} \quad d_2' = \frac{(d_2)^2}{2z}
\]

Also
\[
d_2 - d_2' = (d_2) \left[ \frac{1}{2} - \frac{1}{d_2 + z} \right]
\]

From which we get
\[
d_2 - d_2' = N \lambda = (n \lambda f_0 z)^2 \left[ \frac{1}{2z} \left( \frac{1}{d_2 + z} \right) \right]
\]

From which we get
\[
z = \frac{2N}{(n f_0)^2 \lambda - \frac{N}{2}}
\]

We see that for collimated beam \( 0 \rightarrow 0 \) and \( z = \frac{2N}{(n f_0)^2 \lambda} \)

To test this equation, an experiment was set up with a
1 February 1968

fundamental

Rambli ruling (grating) having spatial frequency of 3.2 lines/mm and this was inserted in a diverging laser beam. The pattern repeated itself at distances as predicted by the equation on the previous page. It was also observed that at distances at which \( d - d' = \pm \frac{\lambda}{2} \) the field became almost uniformly bright with pulse-like dark lines at the edges of the lines in the ruling. Looking at Fourier spectrum of the grating, one could see odd and also weaker even frequencies to be present. A total of 70 orders could be seen on one side of the d.c. term.

Juris Upatnieks, 1 February 1968.

23 April 1968

The production of phase gratings.

For the purpose of testing the concepts of self-imaging gratings and their use to produce uniform amplitude fields, phase gratings had to be constructed with spatial frequencies in the range 3 to 10 lines/mm. It was decided to produce these by bleaching photographically recorded gratings, using the standard Kodak R-10 bleach. A number of techniques were tried.

The Mach-Zehnder interferometer was set up to form low-frequency interference patterns using collimated light. The bleached grating was very noisy due to phase errors introduced by bleaching scattered light patterns from dust and bubbles in the glass. This effect could be reduced by using spatially incoherent light and employing some

Juris Upatnieks, 23 April 1968.
wavefront matching system. Another way would be to use an unbleached grating and image it using incident light and filtering in the transform plane. These techniques seemed somewhat cumbersome and were not tried experimentally.

A good and simple way to produce gratings was found by simply contacting printing plastic rulings at first, with surface of the ruling touching the 649E. The emulsion too high spatial frequencies were created and uniform amplitude field could not be attained. This was so because the bleached pattern was essentially a phase step function. Improved results were attained by spacing the ruling 1/8 to 1/32 in. away from the emulsion and using a broad diffuse light source for illumination. An enlarger with lenses removed and at maximum height, the most suitable grating was obtained with 1/32 in. spacing and exposed to give a density of 0.1.0 before bleaching.

To get better dispersion of wave effects, a crossed grating is desirable. Difficulty was encountered at first because the crossed grating seemed to have aberrations and each orientation would come to focus at a different plane. Using a cylindrical lens correction could be made for one "in-focus" plane, but not for all. It was found that this was caused by the two gratings not being exactly perpendicular to each other. Finally, two separate one-dimensional gratings were used and alignment was done by observing some focal plane, with the more distant planes being more sensitive to misalignment. We also observed that if two gratings are present at 60° angle, then uniform field intensity occurs every other "focal" plane of a single grating, and for a 45° angle it is every third plane.

Jari's Upatnicks, 23 April 1968
The following phase gratings were made during the months February through April 1968. In all cases the standard Kodak R-10 bleach was used to bleach the recorded interference or intensity pattern.

<table>
<thead>
<tr>
<th>Plate #</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>Contact print of Ronchi rulings, 4, 6, 8, and 10 l/mm Exposure very light and phase modulation small</td>
</tr>
<tr>
<td>#2</td>
<td>Same as above, contact print, higher density and greater phase modulation</td>
</tr>
<tr>
<td>#3</td>
<td>Interference pattern of 10 l/mm and 5 l/mm made with Mach-Zehnder interferometer. Gratings have high noise level. Made 6 Feb. 1968.</td>
</tr>
<tr>
<td>#4</td>
<td>Same as #2, different print.</td>
</tr>
<tr>
<td>#5</td>
<td>Contact print of 4, 6, 8, and 10 l/mm Ronchi rulings, 0.01 in. space to give reduced spatial resolution. Made 6 Feb. 1968.</td>
</tr>
<tr>
<td>#6</td>
<td>Same as #5 but with 1/8&quot; spacing. Print illuminated with enlarger having lens removed and enlarger housing at top position.</td>
</tr>
<tr>
<td>#7</td>
<td>Contact double print 4, 6, 8, and 10 l/mm Ronchi rulings, gratings crossed. 1/8&quot; in. space.</td>
</tr>
<tr>
<td>#8</td>
<td>Contact print of Ronchi ruling, 9 lines/mm, 1/8 in. space, one-dimensional grating</td>
</tr>
<tr>
<td>#9</td>
<td>Same as #8, 1/8 in. spacing, exposed for 0.2 s.</td>
</tr>
<tr>
<td>#11</td>
<td>Contact print of Ronchi ruling, 2 l/mm crossed grating, exposed for T = 8%, 1/2 in. spacing</td>
</tr>
</tbody>
</table>

Juris Upatnieks, 25 April 1968
25 April 1968

<table>
<thead>
<tr>
<th>Plate #</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>#12</td>
<td>Contact print of Ronchi ruling, 82 lines/in. spacing, exposed for a density of $D = 2.6$. Made 1 April 1968.</td>
</tr>
<tr>
<td>#13</td>
<td>Contact print same as above, exposed for $D = 2.1$. Made April 1, 1968.</td>
</tr>
<tr>
<td>#14</td>
<td>Contact print of Ronchi ruling, 82 lines/in. spacing, exposed for a density of $D = 1.93$.</td>
</tr>
<tr>
<td>#15</td>
<td>Same as #14 but with 1/32 in. spacing, exposed for a density of $D = 1.93$.</td>
</tr>
</tbody>
</table>

Juris Upatnieks, 25 April 1968

25 April 1968

Experiments with self-imaging phase plates (gratings) to improve two-dimensional image quality.

The idea of using phase modulated wavefronts to illuminate transparencies was described and carried out in practice before. The disadvantage of using random phase plates was that any noise introduced before the phase plate was not eliminated in the output. Also, the transparency had to be in contact with phase plate or a lens relay system had to be used.

As suggested by E.W. Beith, both of the above difficulties could be eliminated using a self-imaging phase plate, such as regular phase gratings. With these phase modulator plates uniform amplitude fields can be obtained at regular intervals away from the modulator (see p. 131).

Juris Upatnieks, 25 April 1968
This way any noise introduced before the transparency or after it gets suppressed. To demonstrate this characteristic the experiments were performed with the optical system shown below:

Two separate one-dimensional gratings were used because these could be aligned more exactly to obtain better aberration-free imaging of the uniform amplitude field at regular intervals. The aperture was inserted after the imaging lens to limit the bandwidth of the diffuse illumination. The spectrum of the crossed gratings is shown below.

The spacing between points represents 30/μm spatial frequency. Exper. time was 10 usec., and good recording could also be made with 150 usec.exper. Photograph made on 3 April 1968.

Juris Upatnieks
25 April 1968
25 April 1968

Plain wavefront illumination (Experiment conducted on 3 April 1968)

Plane-modulated wavefront from two crossed phase gratings, 160 mm away from client phase grating (Experiment conducted on 3 April 1968)

Random phase-modulated wavefront illumination. Film-mod. in contact with transp. (Experiment conducted on 3 April 1968)

Diffuse wavefront illumination with 9 mm film, restricting aperture of Fourier transform plane (Experiment conducted on 3 April 1968)

Juris Upatnieks, 25 April 1968.
Experiments with filters at the output (image) plane of an optical system.

A number of experiments were performed with wedges (filters) at the image plane of an optical system shown below:

The wedges were made by imaging the desired crossed grid pattern on plane $P_1$ and recording it on Kodak 649F film on 4 x 5 x 1/8 glass plates. The plates were then developed in Kodak D-8 developer (2 parts H2O to 1 part of D-8), by controlling the exposure time pattern consisting of dark lines or black dots could be obtained. The patterns were then contact printed on similar glass plates with Kodak 649F emulsion and were developed in Kodak D-8 (1 part of H2O and 2 parts D-8) The developed and fixed plates had brownish appearance. The resulting pattern was these:

- Crisscross grid
- Dot pattern

Mark dimensions:

- Dot diameter: 0.174 mm
- Dots per linear spacing: 0.70 mm
- Line width: 0.13 mm

When used, again the wedge was placed in plane $P_2$ and the recording film distance $W$ behind it.

Juris Vlangenuiks, 29 April 1968.
29 April 1968

The alignment of the mask was quite critical. When properly aligned, a uniformly bright field emerged from the mask. The effect of air currents was visible as darkened waves passing across the field, similar in appearance to those when Mach-Zehnder interferometer is set for zero fringe frequency and one path is disturbed.

The two photographs below show the effect of placing the object transparency in plane of the grid pattern and uniform amplitude field.  

Object transparency in plane of grid pattern, recorded with \( D = 100 \, \text{mm} \). No noise added to the system. 1/2 sec exposure. Experiment performed on 23 April 1968. Grid mask in plane.

Object transparency in plane of uniform amplitude field, image recorded with \( D = 100 \, \text{mm} \). No noise added, grid mask in place, 1/2 sec exposure. Experiment performed on 23 April 1968.

Juris Upatnieks, 29 April 1968
Image made with $D = 130 \text{mm}$, grid mark in place, object transparency in uniform amplitude field. 1 sec. exposure. Experiment performed on 29 April 1968.

Image recorded at four of object, no mask. Object at plane of four grid pattern. 0.5 sec. exposure time. Experiment performed on 29 April 1968.
For all of the experiments with results *1 to *6,  
two crossed phase gratings were used. For *1 and *2 an  
extra noise was used. Besides, the rectangular slit on  
leaves; for *3 to *6, noise was added with a = b = 30 mm,  
except for *5 a = 50 mm and b = 30 mm. The vertical  
pattern is from noise before the transparency and  
horizontal is from noise behind transparency.  
It seems that *5 looks better than *3 or *4.  
The appearance of both *3 and *4 would probably  
be improved if a mask was used also at the  
input.

Juris Upatnieks, 29 April 1968.

2 May 1968

The use of phase grating to improve images  
in spatial filtering systems.

The previous experiments show that improved  
image quality can be attained with wavefront  
having uniform amplitude and periodic phase structures.  
At the Fourier transform plane a rectangular  
array of spots appear due to the crossed phase  
gratings. Let us call this $H(x_1, y_1)$ and the  
transform of the transparency $E(x, y)$. If the  
transparency is illuminated by light coming  
from a crossed phase grating, then the resulting  
spectrum is $H \ast E$. If $H$ is a two-dimensional  
array of delta functions, then convolution with  
$E$ results in a well-separated redundant spectra  
of the signal (if the frequency of grating is properly  
chosen). This or redundant spatial filter could  
be constructed to perform some operation on  
the input signal multiplied by the periodic phase  
structure. The output of such filtered signal  
should be improved just like the unfiltered  
image is.

Juris Upatnieks, 2 May 1968.
Self-Imaging Phase Plates.

On page 131 of this notebook the distances at which a grating images itself was calculated for both collimated and diverging spherical wavefronts. The distance $Z$ for the $N$'s plane and $n$'s harmonic was given as

$$Z_n = \frac{2N}{\lambda (n\delta_0)^2} \text{ for } DZ = 2\pi m, m>0$$

Experimental observations have shown that uniform amplitude wavefronts appear not only for $DZ = 2\pi m$ or phase shift of multiple of $2\pi$ radians, but also for $DZ = \pi m$, or phase shifts of half wavelength for odd multiples of fundamental frequency and full wavelength shifts for even multiples of fundamental frequency. This is true for both single phase gratings and for crossed gratings at right angles to each other.

The distance $Z_n$ will now be calculated for crossed gratings not at right angles to each other and having different special frequencies. We shall assume that uniform amplitude will be observed if all the Fourier transform components are shifted by a multiple of $2\pi$ radians. The following geometry will be used:

$$f_n^2 = (n\delta_0 + m\delta_2 \cos \Theta)^2 + (m\delta_2 \sin \Theta)^2$$

Juris Ulpatieks, 17 May 1968
17 May 1968

(2) \[ f_{n,m}^2 = f_1^2 + n^2 f_1^2 + 2nm f_1 f_2 \cos \Theta + m^2 f_2 \cos^2 \Theta + m f_2 \sin \Theta \]

(3) \[ f_{n,m}^2 = n^2 f_1^2 + m^2 f_2^2 + 2nm f_1 f_2 \cos \Theta \]

A uniform amplitude field will result whenever each of the three terms of eq. (3) will be shifted by a multiple of 2\pi radians in phase with respect to each other and the \( f_{0,0} \) term. For the case where \( f_1 = f_2 \), we can simplify to

\[ f_{n,m}^2 = f^2 \left[ n^2 + m^2 + 2nm \cos \Theta \right] \]

where \( f \) is the fundamental frequency component of the gratings. We find the smallest \( z_i \) for separation between planes as follows: let \( z_0 = \frac{1}{4} f_1 \), which is the separation required for the \( f_{1,0} \) or \( f_{0,1} \) frequency. Assume that \( 2\pi \) shift required for intermediate terms. Then \( z_i \) is given by

\[ z_i = \frac{2z_0}{2\cos \Theta} = \frac{z_0}{\cos \Theta} \]

where \( i \) must be an even number.

This relation has been verified experimentally. The following is a list of observed \( z_i \) and angles \( \Theta \):

<table>
<thead>
<tr>
<th>( \Theta )</th>
<th>( \cos \Theta )</th>
<th>( z_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>60°</td>
<td>( \frac{1}{2} )</td>
<td>2 ( z_0 )</td>
</tr>
<tr>
<td>70°</td>
<td>( \frac{1}{3} )</td>
<td>3 ( z_0 )</td>
</tr>
<tr>
<td>48.2°</td>
<td>( \frac{2}{3} )</td>
<td>3 ( z_0 )</td>
</tr>
<tr>
<td>78.5°</td>
<td>( \frac{1}{5} )</td>
<td>5 ( z_0 )</td>
</tr>
<tr>
<td>66.4°</td>
<td>( \frac{2}{5} )</td>
<td>5 ( z_0 )</td>
</tr>
<tr>
<td>53.1°</td>
<td>( \frac{3}{5} )</td>
<td>5 ( z_0 )</td>
</tr>
<tr>
<td>36.9°</td>
<td>( \frac{4}{5} )</td>
<td>5 ( z_0 )</td>
</tr>
</tbody>
</table>

The requirement for different minimum plane shifts for each grating frequencies (\( f_{0,0} \) and \( f_{0,m} \)) is not and the shifted frequencies \( f_{n,m} \) is not clear at this time.

Juris Zipsnickis, 17 May 1968
Increasing the visibility of holograms made with restricted viewing aperture.

Holograms were previously described which had a real aperture from which the whole image could be viewed. This aperture is usually much smaller than the hologram itself and thus restricts the direction from which a hologram can be viewed. We can alleviate this restriction somewhat by producing similar images side by side, that is, repeating the same scene and perspective over many times. This type of image could be obtained by illuminating the hologram with several beams of light, or alternatively, producing the equivalent by placing a diffraction grating between the illuminating source and the hologram, as shown below:

We would then have aperture A reproduced at A', A'', and so on. This would require that incident light appear to come from sources such that angles α', α'', etc. are formed. For $z_g = 0$ we find that spatial frequency $f$ of the grating should be

$$f = \frac{q}{2z} \lambda = \frac{q}{2} \lambda = \frac{q}{2\lambda}$$

This equation should hold for any $z_g$ except that narrower spread from the source is required if $z_g$ is small.
21 May 1968

If a similar spread is desirable in the other dimension, then another grating may be oriented to produce images of the aperture in that direction. A crossed phase grating would accomplish this.

Separation of apertures may also be achieved by using several wavelengths of light. In that case \( \alpha = \lambda_1 - \lambda_2 = \frac{\lambda_2}{f} \), where \( f \) is the carrier frequency of the hologram and \( \lambda_1 \) and \( \lambda_2 \) are the wavelengths used in reconstruction.

Juris Upatnieks, 21 May 1968

21 June 1968

Bleaching of Holograms.

Several holograms have been bleached which have given much brighter reconstructions with only slight increase in noise level. We have used \( K_3Fe(CN)_6 \) black, modified Kodak R-10 bleach with \( KBr \), and combination bleach of \( K_3Fe(CN)_6 \) and modified \( R-10 \) bleach. Several "Live" holograms were bleached in \( K_3Fe(CN)_6 \) and since many such holograms are available, comparison of brightness could be made. The measurements were made as follows:

![Diagram of hologram, image plane, photomultiplier, and voltmeter]

The measurements were made about 40 cm from the hologram and slight adjustments in distance from the hologram were made so that

Juris Upatnieks, 21 June 1968
the object size would be constant in each case. The density of unbleached hologram was 2.0 = 0.8 to 1.2.

of bleached hologram same before bleaching, and of third hologram also bleached, 1.2 to 1.5. The
measured lightness were as follows:

- Unbleached hologram: 6.2 mV
- Bleached, light, hologram: 20.0 mV
- Bleached, darker, hologram: 40.5 mV

The last hologram, with density of 1.2 to 1.5 and bleached, was brightest of all but was rather noisy.

The lighter bleached one was three times brighter and did not have any degrading noise effects.

From graphs of diffraction efficiency vs. transmission before bleaching of plain gratings, the light hologram
corresponds to efficiency of about 10% and the other to about 15%. Due to the unequal beams and
some scattered incoherent light, the overall efficiency of bleached holograms should be lower.

This photograph shows virtual image reconstructed of bleached lower density hologram. The image
appears sharp and noise-free.

Juris Ugpatrieles
June 21, 1968.
Experiments with pseudo-random phase plates (pattern calculated).

Experiments were conducted during the month of May and beginning of June with the calculated phase plate of Emmett H. Smith. The following photographs show the experimental results and the diagram below shows the schematic of the optical system:

![Diagram of optical system]


Spectrum of filtered pseudo-random phase plate. The photographs on the next page were made with a filter passing the spectrum shown here. 1/5 sec. exposure. Photograph made on 29 May 1968.

Juris Upatnieks, 25 June 1968
Photograph of an imaged transparency illuminated with spectrum shown on previous page. A wire was added. Imaging was done with a 106 mm. Baltar lens. Transparency at plane P2. Photograph made on 24 May 1968.

Some as at left except wire added before and after transparency. Photograph made 24 May 1968.

Filtered spectrum of pseudo-random phase plate. This spectrum was allowed to pass and form a wavefront to obtain the clear fields shown on the following page. Photograph made on 30 May 1968.

Clear field at plane $P_2$ obtained with the spectrum on the previous page. Photograph taken on 30 May 1968.

Clear field 19 cm from plane $P_2$ taken obtained with the spectrum on the previous page. Distance of 19 cm corresponds to plane shift of $\frac{3}{4}$ radians. Photograph taken on 30 May 1968.

Juris Upatnieks, 25 June 1968
Measurements of intensities of pseudo-random calculated plane plate.

1 July 1968

Spectral line above d.c. R to R
Scan speed: 1.25 mm/sec
Record speed: 2.5 mm/sec

10 V/div.

10 mV/div.

Spectral line above d.c. K to R

17

14

20

5.5

1.0

1.8

0.5

6°

Photo-multiplier with aperture of about 0.5 x 0.5 mm

Juris Upatnieks, 2 July 1968
These two scans, 3 and 4, are in direction perpendicular to 1 and 2. Slight difference in measured values is probably caused by changing laser output.

The graph on the following page shows scan across image plane of the pseudo-random phase plate with one filtered wide-band.

Junko Uchimura, 2 July 1968
2 July 1968

Filtered pseudo-random phase plate
in focal plane
Chart speed: 2.5 mm/sec.
Scan speed: 1.25 mm/sec.

10 µV/div.

Sanborn Recording Permapaper

1 July 1968
Filtered pseudo-random phase pattern
filtered, in focal plane
Chart speed: 2.5 mm/sec.
Scan speed: 1.25 mm/sec.

10 µV/div.

Lasers

6328 Å

Phase plate

Image plane of P1

Image plane of P2

Junis Upatniks, 2 July 1968