An Investigation of Photographic Phase Holograms

Dale Lance Markham

Western Michigan University

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AN INVESTIGATION OF
PHOTOGRAPHIC PHASE HOLOGRAMS

by

Dale Lance Markham

A Thesis
Submitted to the
Faculty of The Graduate College
in partial fulfillment
of the
Degree of Master of Arts

Western Michigan University
Kalamazoo, Michigan
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Gratitude is expressed to my Thesis Committee Members Professors Nathan L. Nichols and John E. Herman for their constructive criticisms which benefited in the writing of this thesis. Particular thanks goes to my Major Thesis Advisor Professor Stanley K. Derby for his time, patience, and guidance given to me during the many months of this investigation.

Dale Lance Markham
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CHAPTER I
THE PROBLEM AND ITS BACKGROUND

Since the theory and research on holography was first accomplished by Gabor, it was left to Leith and Upatnieks to show that the idea of holography was more than just an optical curiosity. The first holograms were recorded on ultra fine grained photographic emulsions, processed with just a development and a fixing stage. Cathey showed that holograms could also be bleached resulting in an increased brightness of the holographic image. Because a brightness ratio of almost a factor of ten exists between bleached and unbleached holograms, study proceeded in the direction of developing better methods of producing bleached holograms. Other means of producing holograms such as recording the hologram in dichromated gelatin or photoplastics have been developed but because photographic emulsions are at least 100 times faster than other materials and are sensitive to all wavelengths of visible light, most ventures were turned towards photographic holography.

Along with the increase of brightness there are two problems which must be solved before high quality bleached holograms can be produced. The first problem concerns the fact that a photographic emulsion, when bleached, produces an excessive amount of scattered light which degrades the holographic image. A second problem concerns
the fact that the final bleached product is generally left in the form of a silver halide, which exhibits printout darkening as a function of time. As the silver halide reduces back into metallic silver, the hologram darkens and the holographic information is lost. The resultant increase in darkening of the emulsion is known as the printout effect.

It is the purpose of this investigation to attempt to produce bleached holograms which have good resolution and high resistance to printout darkening.
Holography is a radically different concept in photographic optics. The process, which can be called photography by wavefront reconstruction, records the reflected light waves from an object and not the image of the object, being photographed, as with the normal photographic process. The photographic record, called a hologram, bears no resemblance to the original object but contains in an optical code all the information about the object that would be contained in an ordinary photograph and much additional information unrecordable by any other photographic process. The hologram looks like a hodgepodge of specks, blobs, and whorls upon the developed photographic plate or film. The creation of an intelligible image from the hologram is known as the reconstruction process, where the waves optically recorded on the emulsion surface proceed onward reconstructing an image of the original subject, oblivious to the time lapse in their history. These waves are indistinguishable from the original waves and are capable of all the phenomena that characterize the original waves.

As in ordinary photography, the object is illuminated and a photographic emulsion positioned to receive reflected light from the object. However, no lens or other image
forming device is used in creating a hologram. Each point on the emulsion receives light from the entire object; conversely, each point on the object reflects light to the entire photographic emulsion. The illuminating light must be monochromatic and coherent, also different from ordinary photography. Lastly, a mirror is used to direct a portion of the coherent light directly to the plate, bypassing the object. This beam is called the reference beam, and it is the interference effect between it and the reflected object light which creates the hologram.

The problem of wavefront reconstruction is to record the exact form of the wave pattern reflected from an extended and irregular object. To capture the wave pattern completely both the amplitude and the phase of the waves must be recorded at each point on the emulsion surface. Ordinary photographic emulsions record wave amplitudes by conversion of the amplitudes to corresponding variations in the opacity of the emulsion. The emulsion, however, is completely insensitive to phase relations. The technique of interferometry is used in holography to preserve these phase relations. It can be shown that relative phase information can be preserved in two-beam interference patterns. The basic technique of hologram formation then is to divide the coherent light coming from a laser into two beams; one to illuminate the subject and one to act as a reference beam. The reference beam usually has a spherical or planar
wavefront. The reference beam is directed to intersect the light reflected from the subject. Since these two beams are coherent, an interference pattern will form in the volume of space where the beams overlap. A photographic emulsion placed in the overlap region thus records the amplitude and phase relations from the reflected light originating from the subject. After suitable processing of the emulsion, the medium becomes the hologram.

The intensity of the interference pattern can be regarded as a three-dimensional contour map. If the photographic emulsion in the overlap region is very thin, it will record line traces of the maximum intensity contour surfaces. Such holograms are called plane holograms and these holograms have properties similar to those of plane diffraction gratings. If the photographic emulsion is relatively thick, the contour surfaces themselves are recorded. Such holograms are called volume holograms and these take on properties of volume diffraction gratings. A hologram made in the manner just described has many of the properties of a grating made by a ruling engine; however, such a grating has precise uniformity whereas a hologram has complete nonuniformity. The inadvertently produced irregularities in an imperfectly ruled grating produces false spectral lines called ghosts, while the deliberately induced irregularities in a hologram give rise in the reconstruction process to a complete well
The lines of developed silver on plane holograms and the surfaces of developed silver on volume holograms are very closely spaced and therefore diffract light significantly. When the hologram is illuminated by the original reference beam, part of the light diffracted out of the reference beam is directed and shaped by the hologram into a re-creation of the light wavefronts originally coming from the subject. A reconstructed wave train proceeds out from the hologram exactly as did the original subject wave. An observer viewing a wave identical with the original subject wave perceives it to diverge from a virtual image of the subject located precisely at the original subject position. If the reference beam is accurately positioned so that all rays of the reflected beam are opposite to the original reference beam, then a real image of the subject at the original subject location is produced. Because the light converges to the image it can be directly detected with a photographic emulsion without need for a lens. In summary, a hologram acts as a combination recording and projection system which provides an image of the original subject when illuminated by the reference and does so without the need for additional lenses.

Holograms and the images they produce have many curious and fascinating properties. The pertinent information recorded on the hologram can be seen only under
magnification and consists of highly irregular fringes which bear no apparent relation to the subject. A hologram can be broken into small fragments and each fragment will produce a complete image. However, as the pieces get smaller, the image resolution is lost. The hologram is itself a positive, not a negative. Normally one would consider a hologram as a negative, but the image it produces is a positive. The photographic emulsion containing the hologram registers only two levels of density; transparent and opaque. However, the tonal qualities of the image do not suffer. Several images can be superimposed on a single emulsion with successive exposures, and each image can be recovered without being affected by the other images. The virtual image is seen by looking through the hologram as if it were a window. The image appears in complete three-dimensional form. As the observer changes his viewing position the perspective of the picture changes, just as if the observer were viewing the original scene. Parallax effects are evident between near and far objects. If an object in the foreground lies in front of something else, the observer can move his head and look around the obstructing object to see the previously hidden object. One must refocus his eyes when the observation is changed from a near to a far object. In short, there are no visual tests one can make to differentiate the image from the real object. The real image will hang in space between
the observer and the hologram also having all of the above mentioned features; however, this real image is much more difficult to view.

The light used to illuminate the object must be both coherent and monochromatic. If the spectrum of the light was broad, each wavelength component would produce its own separate pattern and the resultant of all these components would average out the fringes and produce a smooth distribution. Thus the requirement for a monochromatic source. If the source is non-coherent, then each source element produces interference fringes displaced from those of other elements; thus, the sum of many such sets of fringes averages to some very nearly uniform value, thus losing the desired fringe pattern.

Holography was intended as a tool for electron microscopy. It occurred to Gabor in 1948 that the aberrated image produced by an electron lens still preserves all of the subject information but in a somewhat coded form. If the aberrated image could somehow be decoded, the resolution limit of the electron microscope perhaps could be increased by a factor of ten. Gabor dispensed with the microscope altogether and performed a decoding operation on a photographic record of unfocused electron waves diffracted from the subject. He theorized that this wave record could be decoded by illuminating it with coherent visible light; thus, waves arising out of the diffraction
yield the optical equivalent of the unfocused electron waves. These waves should yield a highly magnified optical image, the magnification being given by the ratio of the light wavelength to that of the electron wavelength. The light beam must be an accurately scaled imitation of the electron waves. Gabor formed the first hologram with visible light to test his theory. At that time, and even now, it is not possible to obtain the required beam coherence in an electron wave and difficulties also exist in high resolution recording at very short wavelengths.

Before the invention of the laser, the concept derived by Gabor seemed to be doomed to a class of optical curiosities. Due to the many obstacles, little progress was made and the concept abandoned for nearly a decade. However, in the early 1960's Leith and Upatnieks brightened prospects in holography, by employing the newly developed laser which provided a very intense, monochromatic, coherent light source. By 1964 they had convincing proof that holography was indeed practical. This was a long step from Gabor's idea of wavefront reconstruction.

Several imaginative applications seem to rest in the balance if holography can be improved. One specific application seems to lie in the areas of electron or x-ray holography as first proposed by Gabor. Holograms recorded in these electromagnetic frequencies may theoretically be reconstructed in visible light. The most sensational
future application of holography undoubtedly lies in the field of producing three-dimensional television and motion pictures; however, technical problems must be surmounted before these forms of entertainment become a reality.
CHAPTER III

PROPERTIES OF PHASE HOLOGRAMS

In optical holography a photographic emulsion is used to record the sum of the wavefronts from the object and from a reference beam, the reference beam making possible the recording of both the amplitude and the phase of the object wavefront. The amplitude of the object wavefront is represented by the intensity of a fringe pattern recorded by the density of developed silver sites while the phase of the object wavefront produces variations in the position of the fringes. The resulting holographic image is due in part to the different amplitudes of metallic silver developed on the photographic emulsion. Such a hologram is sometimes called an amplitude hologram, since in reconstruction of the image, the photographic emulsion spatially amplitude modulates the wavefront of the illuminating beam in a way to reconstruct the original wavefront from the object.

Analogous to a modulated carrier in electrical communications, Cathey\textsuperscript{5} first developed the idea that spatial phase modulation could replace spatial amplitude modulation in reconstruction of the holographic image. If an amplitude hologram is bleached, so as to convert the metallic silver to a transparent compound whose index of refraction differs from that of the gelatin, then the holographic record is
written in the resulting localized changes in the index of refraction of the emulsion. Such a hologram is sometimes called a phase hologram, because the holographic information is now due to a spatially phase modulated wavefront.

Since Cathey\textsuperscript{6} first bleached a photographic plate and showed that phase holograms add more flexibility to the wavefront reconstruction process, other methods of producing pure phase holograms have been developed. Materials other than bleached photographic emulsions for producing phase holograms include: dichromated gelatin\textsuperscript{(7-11)}, photopolymer\textsuperscript{(12-16)}, thick thermoplastics\textsuperscript{(17,18)}, photoresist\textsuperscript{(19-24)}, iron oxide\textsuperscript{(25,26)}, photoplastics\textsuperscript{(27-29)}.

Two terms are useful in describing properties of holograms: these are diffraction efficiency and signal to noise ratio. These terms may be applied equally well to either amplitude or phase holograms. The brightness of a holographic image can be described by the term diffraction efficiency which is defined as the amount of light diffracted by the hologram into making the holographic image, divided by the incident light upon the hologram. Diffraction efficiency is usually expressed as a percentage. The resolution of a holographic image can be described by the term signal to noise ratio, which is defined as the ratio of the intensity of the diffracted light originating from the object as compared to the intensity of the scat-
tered light originating from the background.

Holograms suitably processed in dichromated gelatin\textsuperscript{30} have diffraction efficiencies of as high as 90\% and signal to noise ratios of 230 to 1. These holograms have good environmental stability but their spectral sensitivity is limited to the short wavelengths. Holograms suitably processed in photopolymer materials\textsuperscript{31} have diffraction efficiencies of as high as 80\% and signal to noise ratios of 200 to 1 but the environmental stability of photopolymer materials must be improved. Holograms suitably processed in thick thermoplastics\textsuperscript{32} have diffraction efficiencies of 25\% and signal to noise ratios of 70 to 1 but the material distorts at high temperature and humidity and is not very sensitive at long wavelengths. Holograms suitably processed in photoresist materials\textsuperscript{33} have diffraction efficiencies of 80\% and signal to noise ratios of 250 to 1 but humidity causes fine cracks to form in the photoresist material. Holograms suitably processed in iron oxide materials\textsuperscript{34} have excellent stability against all environmental parameters but the maximum diffraction efficiencies are 20\% and signal to noise ratios 15 to 1. Holograms suitably processed in photoplastics\textsuperscript{35} have good environmental stability and sensitivity at long wavelengths but diffraction efficiencies of only 10\% and signal to noise ratios of 45 to 1 have been reported. Burckhardt\textsuperscript{36} has shown that theoretically it is possible to produce bleached photographic holograms with
100% diffraction efficiency, whereas the maximum possible
diffraction efficiency of unbleached photographic holograms
is about 4%. Latta\textsuperscript{37}, and Upatnieks and Leonard\textsuperscript{38} have
produced bleached photographic holograms with diffraction
efficiencies of about 60%.

Because of their high sensitivity to light, especially
at long wavelengths, photographic emulsions are still
preferred for recording holograms. When a photographic
emulsion is developed, fixed, and then bleached, the plate
or film is rendered almost transparent. Because of reduced
attenuation of light, spatial phase modulation methods are
capable of producing a brighter image than spatial ampli-
tude modulations.

The phase modifications to the incident beam can be
caused by an index of refraction variation in the emulsion
or by relief images on the emulsion surface. Variation of
the index of refraction is proportional to the mass of
silver originally exposed, thus the more silver sites
originally exposed and converted to a transparent material,
the greater the change in the index of refraction. Since
the mass of silver is proportional to the silver density,
holograms which demonstrate high diffraction efficiencies
when bleached have high original densities. Variation in
the relief image height is also proportional to the origi-
inal silver density as well as dependent on the tanning
action produced on the gelatin by the developer and the
bleach. Tanning is the result of a higher than normal
degree of cross linking of the gelatin molecules due to
chemical treatment of the emulsion. Tanning causes the
gelatin layer to become insoluble in water. Upon drying,
that area of the gelatin receiving a greater degree of
tanning becomes thicker than the less tanned area because
the amount of water absorption, and hence the volume
expansion, decreases with increased tanning.

Unfortunately, while bleached photographic holograms
have high diffraction efficiencies, the improved efficiency
is accompanied by an increase in scattered light reducing
the image resolution. Also, the materials remaining in
the emulsion are very prone to convert back into metallic
silver (printout effect), rendering the hologram darker
and the holographic image of lesser quality. Several
reasons have been proposed for the poor resolution quality
of a bleached holographic image: local changes in emulsion
thickness on development due to release of stress intro­
duced by factory drying, tanning of the emulsion by the
developer and bleach, stress formation during the drying
of the emulsion, silver being extruded from geometrically
regular positions to filamentary tangles in developing,
scattering by the large silver halide grains, optical
irregularities or phase errors within the volume of the
emulsion, localized lateral distortions that vary according
to the grain pattern of the signal beam.
All of the above factors are contributors to the scattering of light in bleached holograms which is classified as optical noise. Methods of controlling the printout effect as well as lowering the optical noise in photographic phase holograms must be found before an optimum process can be reported.
CHAPTER IV

EXPERIMENTAL ARRANGEMENT

Hologram Camera

The holograms were exposed in a hologram camera known as a "sand box unit". The unit is so named because the laser and the lenses and mirrors which diverge and reflect the laser beams are simply placed into a box full of sand. The box is a table turned upside down which has a retaining wall of six inch depth which is filled with sand. The box is placed upon a truck tire inner tube which is not fully inflated. The tube in turn lies on another table which isolates the system from the floor and walls. The tube is not fully inflated to better act as a vibration damper. The box is isolated from the floor and walls to prevent vibrations from entering the system. The laser, lenses, and mirrors are placed in the sand as a further precaution against vibration (figure 1).

The components of the hologram camera were arranged as in figure 2. The laser was a Bausch and Lomb He-Ne Gas Laser\(^3\) which produced a beam of 0.6 milliwatts full intensity at 6328 angstroms. A black box was positioned over the laser with only a hole to let the beam out in order to cut out the background glare produced by the laser. The reference beam to stage illumination ratio was 1.5 to 1, and the angle between these beams was 60 degrees. The
Figure 1. The Sand Box Unit

Figure 2. Arrangement of Components in The Sand Box Unit

Figure 3. Arrangement of Transparency Measurement Zones on each Hologram
stage consisted of a series of spikes for estimating signal to noise ratio of the holographic image as well as the backside of a Kennedy half dollar for determining the resolution properties of the image.

The hologram box was placed in a photographic darkroom where no light or air currents could enter. To expose a hologram a black piece of cardboard was placed in front of the laser beam, the unexposed film was positioned by means of clips onto the film platform, the system was allowed to rest for thirty seconds so that vibrations were damped out, then the cardboard was carefully raised to allow the beam to enter the system. After the proper exposure time the cardboard was lowered blocking off the beam and ending the exposure. The hologram was then processed immediately in a separate darkroom.

Transparency Measurements

The method of determining the transparency of holograms was straightforward and simple. After the hologram was processed, five circles one-eighth inch in diameter were drawn on the non-gelatin side of the hologram (figure 3). Each small circle of the hologram was then oriented in turn in a Bausch and Lomb Microphotometer and the transparency of the small circular area was measured. The working value for each hologram transparency was taken as the average of the five values recorded for the five circular areas. The holograms were then

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placed on a light box of diffused fluorescent light (intensity 145 foot-candles) for twenty-four hours a day. Any evidence of printout darkening could be detected if after a given period of time a further check of the holographic transparency showed changes, the assumption being that the changing transparency of the hologram is directly related to the phenomenon of printout darkening.

Duplicate holograms were generated for each modification of the various parameters of developing, bleaching, clearing, and desensitization. Each duplicate hologram pair resulted in printout versus time curves that were very similar. Because of this similarity, the duplicate measurements for each pair were averaged and plotted as a single curve.

The absolute percentage of transmitted light was plotted as a function of time to determine the transparency variation of each modification. The higher the transparency of the modification, the more likely it is for the hologram to have a high diffraction efficiency. The normalized percentage of transmitted light was plotted to determine the printout variation of each modification as a function of time. The lower the printout resistance of the modification, the more likely it is for the holographic image to suffer a degradation. The absolute percentage of transmitted light is read directly from the microphotometer. The normalized percentage of transmitted
light is found by dividing the holographic transparency as a function of time by the initial holographic transparency.
CHAPTER V

STUDIES IN BLEACHING PROCESSES

Techniques for Producing Photographic Phase Holograms

A search was made in the literature for ways of producing high quality photographic phase holograms. It was found that several groups had evolved their own particular means of processing. Of these processes, each can be placed into one of three categories for production of photographic phase holograms. These categories are: 1) direct bleaching process, 2) negative phase image process, 3) reversal bleaching process.

In a typical direct bleaching process the emulsion is developed and fixed, then bleached in a solution that converts the metallic silver into a transparent, insoluble salt having a refractive index significantly higher than that of the gelatin. When the emulsion dries, a relief image is formed where the developer converts the silver halide into metallic silver. The tanning tends to be fairly localized within the emulsion and as a result the emulsion pulls together. For a direct bleaching process the variations of optical path length from the relief image and those from index variations within the emulsion are additive, consequently excessive optical noise is produced upon the reconstructed image.
In a typical negative phase image process, the exposed emulsion is developed but not fixed so that silver halide remains in the unexposed regions. The emulsion is then bleached in a suitable bleach bath which converts the metallic silver to a soluble salt and removes it from the emulsion. Because the remaining silver halide appears as a negative for a direct process, this is referred to as a negative phase image process. In a direct bleach process the formed relief image enhances scattered light. However, the negative phase image process keeps the relief image path length variation of light to a minimum. This drastically reduces the optical noise in the holographic image. Maximum tanning occurs in regions of maximum development and thus there is a tendency for a relief image to be formed at the position of the silver sites. However, the bulk of the silver halide tends to counteract this effect and for commonly used developers this bulking seems to be the stronger effect.

In a typical reversal bleach process the exposure and development of the hologram are carried out to form a normal silver image. The hologram is then re-exposed to a uniform source of white light making developable the silver halide grains not protected by the previously formed silver image. The hologram is bleached after the second development, thus the metallic silver formed in either development is removed leaving a phase image formed
only from the residual silver halide. If the second 
exposure is controlled, almost the entire background of 
silver halide grains can be eliminated leaving a phase 
image consisting of the silver halide grains shielded by 
the silver formed from the first exposure. It is intuitively 
obvious that reduction of this background would 
reduce the scattered light inherent in a bleached holo-
graphic image. Figure 4 shows schematically the three 
previously described processes.

Of the processes described in the literature five 
were selected for investigation in this paper because of 
the claims that each processed holograms of high diffraction efficiencies, high signal to noise ratios, and high 
resistance to printout. These processes were: 1) The 
Modified Stanford Process, 2) The Kodak Reversal Bleach 
System, 3) The Modified Developer Process, 4) The 
The following experimental work is directed towards exam-
ing each process in detail and combining the good features of these five methods into an optimum process for 
creating photographic phase holograms. Table I categorizes 
each process investigated in this paper.

The Modified Stanford Process

The Modified Stanford Process is a result of modifi-
cations on The Stanford Process. The Stanford Process was
<table>
<thead>
<tr>
<th>Direct Bleach Process</th>
<th>Negative Phase Image Process</th>
<th>Reversal Bleach Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Expose</td>
<td>1) Expose</td>
<td>1) Expose</td>
</tr>
<tr>
<td>[ AgBr ] Base</td>
<td>[ AgBr ] Base</td>
<td>[ AgBr ] Base</td>
</tr>
<tr>
<td>2) Develop</td>
<td>2) Develop</td>
<td>2) Develop</td>
</tr>
<tr>
<td>[ AgBr ] Ag</td>
<td>[ AgBr ] Ag</td>
<td>[ AgBr ] Ag</td>
</tr>
<tr>
<td>3) Fix</td>
<td>3) No Fix</td>
<td>3) Re-expose with uniform white light</td>
</tr>
<tr>
<td>[ Ag ] Base</td>
<td>[ Ag ] Base</td>
<td>[ Ag ] Base</td>
</tr>
<tr>
<td>4) Bleach to convert Ag to a silver halide</td>
<td>4) Bleach to remove Ag</td>
<td>4) Redevelop</td>
</tr>
<tr>
<td>[ AgBr ] Base</td>
<td>[ AgBr ] Base</td>
<td>[ AgBr ] Base</td>
</tr>
<tr>
<td>5) Dry (Arrows represent emulsion movement)</td>
<td>5) Dry (Arrows represent emulsion movement)</td>
<td>5) Bleach to remove Ag</td>
</tr>
<tr>
<td>[ AgBr ] Base</td>
<td>[ AgBr ] Base</td>
<td>[ AgBr ] Base</td>
</tr>
</tbody>
</table>

Figure 4. Schematic of the Emulsion Cross Section for a Direct Bleach Process, a Negative Phase Image Process, and a Reversal Bleach Process
Table I
Categorization of the Five Processes Investigated in this Paper

<table>
<thead>
<tr>
<th>Process</th>
<th>Process Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified Stanford</td>
<td>Direct Bleach Process</td>
</tr>
<tr>
<td>Kodak Reversal Bleach</td>
<td>Negative Phase Image Process</td>
</tr>
<tr>
<td>Modified Developer</td>
<td>Negative Phase Image Process</td>
</tr>
<tr>
<td>Modified Reversal Bleach</td>
<td>Reversal Bleach Process</td>
</tr>
<tr>
<td>Agfa</td>
<td>Negative Phase Image Process</td>
</tr>
</tbody>
</table>

developed by Lehmann, Lauer, and Goodman\textsuperscript{46} at Stanford University. To negate the effects of the relief image formation in a direct bleaching process they introduced a prehardening step immediately after exposure and before development. Lehmann, Lauer, and Goodman\textsuperscript{47} report that the speed of Agfa films decreases in proportion to the prehardening time. However, as the prehardening time increases the diffraction efficiency and signal to noise ratio both decrease. Upatnieks and Leonard\textsuperscript{48} report that Kodak Prehardener SH-5 reduces the relief pattern and localized distortions on Kodak 649-F plates giving better diffraction efficiency and signal to noise ratio. The Stanford Process utilizes cupric bromide as a bleaching agent. Lehmann, Lauer, and Goodman\textsuperscript{49} theorize that the bleach first converts the metallic silver to silver bromide leaving insoluble cuprous bromide in the emulsion. A
clearing bath consisting of a mixture of potassium permanganate and potassium bromide then converts the cuprous bromide back into soluble cupric bromide and also removes the sensitizing impurities from the emulsion leaving a transparent silver bromide medium of refractive index 2.25 in the emulsion. In regard to printout behavior, Lehmann, Lauer, and Goodman\textsuperscript{50} only reported that holograms exposed to rooms lighted by fluorescent lights, sunlight filtered through Venetian blinds, and scanned by a He-Ne and Argon lasers yielded after seventy days no appreciable evidence of printout. Since the final emulsion product is silver bromide, one would expect that a printout would occur fairly rapidly as a function of time, as reported by McMahon and Maloney\textsuperscript{51}.

The Stanford Process was modified by Colburn, Zech, and Ralston\textsuperscript{52} in two ways: 1) an amount of ferric chloride equal to that of the cupric bromide was added to the bleach, 2) a two step drying process of 50\% methanol then 100\% methanol was instituted to insure a more uniform and quicker drying procedure as well as helping clear the emulsion surface of sensitizing impurities. This modified process they named The Modified Stanford Process. The essential processing steps of The Modified Stanford Process are given in Table II.

Holograms processed by The Modified Stanford Process gave brighter holographic images than with any other process.
Table II

The Essential Processing Steps of
The Modified Stanford Process

<table>
<thead>
<tr>
<th>Step</th>
<th>Step Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Preharden in Kodak SH-5</td>
</tr>
<tr>
<td>2</td>
<td>Develop in Kodak D-19</td>
</tr>
<tr>
<td>3</td>
<td>Fix in Kodak Rapid Fixer</td>
</tr>
<tr>
<td>4</td>
<td>Bleach in Ferric Chloride and Cupric Bromide</td>
</tr>
<tr>
<td>5</td>
<td>Clear and Desensitize in Potassium Permanganate and Potassium Bromide</td>
</tr>
</tbody>
</table>

tried in this paper. However, image resolution was not as good as with most of the processes, indicating much scattering of light in the emulsion due either to the bleaching process or to the relief image formed by such a direct bleaching process. No qualitative data were taken on diffraction efficiency or signal to noise ratio.

The printout effect was studied in a much more qualitative manner. The Modified Stanford Process was further altered in this investigation by the omission or substitution of a certain processing step to better understand how each step changes the printout resistance of the emulsion. The first variation of The Modified Stanford Process involved omission of the prehardening step. The second change was the replacement of D-19 with D-76 as
the developer. The third change was the substitution of potassium dichromate as the bleaching agent. Variation number four was the omission of the clearing bath.

Figures 5–8 illustrate the transparency response of the bleached emulsions to the alterations of The Modified Stanford Process while Table III gives the final absolute and normalized transparencies of these alterations.

Table III

<table>
<thead>
<tr>
<th>Final Absolute and Normalized Transparencies of Holograms Processed with The Modified Stanford Process and Processed with the Four Modifications Performed on The Modified Stanford Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute Transparency</td>
</tr>
<tr>
<td>------------------------</td>
</tr>
<tr>
<td>Modified Stanford Process</td>
</tr>
<tr>
<td>Without Prehardener</td>
</tr>
<tr>
<td>Developed with D-76</td>
</tr>
<tr>
<td>Bleached with Potassium Dichromate</td>
</tr>
<tr>
<td>Without Clearer</td>
</tr>
</tbody>
</table>

Figures 5–8 show that although printout is extreme in all modifications within the first week, each modification recovered as time progressed. Although all processes leveled off to a constant transparency after a ten week period, some of the modifications have final transparencies above those of the initial readings. Processing
Figure 5. Time Variation of Absolute and Normalized Transparency of Holograms processed with The Modified Stanford Process (MSP) and processed without the prehardener in The Modified Stanford Process

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Figure 6. Time Variation of Absolute and Normalized Transparency of Holograms processed with the Modified Stanford Process (MSP) and processed with D-76 substituted as the developer in The Modified Stanford Process.
Figure 7. Time Variation of Absolute and Normalized Transparency of Holograms processed with The Modified Stanford Process (MSP) and processed with potassium dichromate substituted as the bleaching agent in The Modified Stanford Process.
Figure 8. Time Variation of Absolute and Normalized Transparency of Holograms processed with The Modified Stanford Process (MSP) and processed without the clearer in The Modified Stanford Process.
without the prehardener yields a higher transparency than processing with the prehardener; however, probably with decreased diffraction efficiency and signal to noise ratio although no measurements were taken. Developing in D-76 yields holograms which are more transparent but more apt to printout than holograms developed in D-19. Holograms bleached with potassium dichromate are almost completely transparent; however, the holographic image is very faint indicating perhaps that potassium dichromate is not a suitable agent for holograms processed with a direct bleach process. Holograms processed without being cleared were very low in both transparency and printout resistance indicating that the potassium permanganate and potassium bromide in the clearer increase the holographic transparency as well as desensitize the hologram to printout. The shape of the curves in Figures 5-8 would seem to indicate that the recovery rates of the curves are independent of any change made in this investigation. Perhaps the sudden printout and gradual recovery is normal to a direct bleach process. Further investigations will be made in this paper to attempt to better understand the behavior of this transparency response.

The Kodak Reversal Bleach System

The Kodak Reversal Bleach System which was developed by Lamberts and Kurtz\textsuperscript{53} utilizes a special developer which produces sufficient tanning action to keep the relief image
path length variation to a minimum, which is the primary function of a negative phase image process. The essential processing steps of The Kodak Reversal Bleach System are given in Table IV.

**Table IV**

<table>
<thead>
<tr>
<th>Step 1</th>
<th>Step 2</th>
<th>Step 3</th>
<th>Step 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Develop in Kodak SD-48</td>
<td>Bleach in Potassium Dichromate</td>
<td>Remove Stains in Potassium Permanganate</td>
<td>Clear in Sodium Bisulfite</td>
</tr>
</tbody>
</table>

The active constituent of Kodak Special Developer SD-48 is pyrocatechol\textsuperscript{54}, which provides a strong tanning action with its high value of pH. The relief image is formed because of the strong local tanning action of the special developer on the gelatin in regions where development to metallic silver takes place. This tanning action causes the gelatin to pull together when drying, increasing the thickness of the emulsion layer relative to other areas. The refractive index variation of the gelatin occurs because the developed silver is removed from the gelatin by the bleach which results in a higher
concentration of the original high index silver halide crystals in regions that received less exposure, and thus, an increase in the refractive index of the emulsion layer.

Lamberts and Kurtz reported a diffraction efficiency of 46% and a signal to noise ratio of 17 when the process was used on Kodak 649-F plates. No mention was made of possible printout darkening.

Pyrocatechol is a hazardous material and when using the developer caution is needed. Rubber gloves seemed unsuitable since several gloves developed leaks after contact with the developer; however, plastic gloves worked very well. The developing stage of this process was very difficult to control. With the Agfa 10E70 film a development time of two minutes was found to give optimum results as to the holographic image. The images obtained were not of particularly high efficiency but the resolution of the images was good. One would expect a high tanning developer such as pyrocatechol to have less of a relief image forming effect on a thin emulsion such as Agfa 10E70 film (about 5 microns) than on a thick emulsion such as Kodak 649-F plates (about 18 microns). Thus a smaller diffraction efficiency and smaller signal to noise ratio might be expected with Agfa 10E70 film, although no qualitative data were taken.

The printout effect was studied in a much more qualitative manner. The Kodak Reversal Bleach System was
further modified in this investigation by the omission or substitution of a certain processing step to better understand how each step changes the printout resistance and transparency of the emulsion. The first variation of The Kodak Reversal Bleach System was the replacement of the special developer with D-19. The second variation was the replacement of the special developer with D-76. The third variation was the omission of the stain remover. The fourth variation was the omission of the clearer. The fifth variation was the omission of both the stain remover and the clearer.

Figures 9-13 illustrate the transparency response of the bleached emulsions to the alterations of The Kodak Reversal Bleach System while Table V gives the final absolute and normalized transparencies of these alterations.

Developing the hologram with the special developer, with D-19, or with D-76 produces transparency and printout behavior responses which are almost indistinguishable. Holograms processed without the stain remover were unchanged in transparency from holograms processed utilizing the stain remover; however, the printout was noticeably less extreme indicating that the potassium permanganate which is the working agent in the stain remover tends to speed printout darkening in the emulsion. Holograms processed without the clearer were much less transparent.
Figure 9. Time Variation of Absolute and Normalized Transparency of Holograms processed with The Kodak Reversal Bleach System (KRBS) and processed with D-19 substituted as the developer in The Kodak Reversal Bleach System.
Figure 10. Time Variation of Absolute and Normalized Transparency of Holograms processed with The Kodak Reversal Bleach System (KRBS) substituting D-19 and D-76 as developers
Figure 11. Time Variation of Absolute and Normalized Transparency of Holograms processed with The Kodak Reversal Bleach System (KRBS) substituting D-19 as the developer and substituting D-19 as the developer along with removal of the stain remover.
Figure 12. Time Variation of Absolute and Normalized Transparency of Holograms processed with The Kodak Reversal Bleach System (KRBS) substituting D-19 as the developer along with removal of the clearer.
Figure 13. Time Variation of Absolute and Normalized Transparency of Holograms processed with The Kodak Reversal Bleach System (KRBS) substituting D-19 as the developer and:
1) processed without the stain remover,
2) processed without the clearer,
3) processed without either the stain remover or the clearer

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Table V
Final Absolute and Normalized Transparencies of Holograms Processed with The Kodak Reversal Bleach System and Processed with the Five Modifications Performed on The Kodak Reversal Bleach System

<table>
<thead>
<tr>
<th></th>
<th>Absolute Transparency</th>
<th>Normalized Transparency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kodak Reversal Bleach System</td>
<td>40%</td>
<td>66%</td>
</tr>
<tr>
<td>Developed with D-19</td>
<td>42%</td>
<td>65%</td>
</tr>
<tr>
<td>Developed with D-76</td>
<td>38%</td>
<td>64%</td>
</tr>
<tr>
<td>Without Stain Remover</td>
<td>39%</td>
<td>74%</td>
</tr>
<tr>
<td>Without Clearer</td>
<td>28%</td>
<td>47%</td>
</tr>
<tr>
<td>Without either Stain Remover or Clearer</td>
<td>32%</td>
<td>67%</td>
</tr>
</tbody>
</table>

and much more susceptible to printout than holograms processed utilizing the clearer. This indicates that sodium bisulfite which is the working agent in the clearer is an important chemical in retaining high transparency and high resistance to printout in The Kodak Reversal Bleach System. Transparency and printout are moderate with holograms processed without either the clearer or the stain remover. This is reasonable since processing without the clearer yields holograms very susceptible to printout and low transparency while processing without the stain remover yields holograms which have the opposite qualities as those just mentioned. The quality of the
holographic images was not noticeably different with any of the above mentioned alterations, although no qualitative data were taken.

The Kodak Reversal Bleach System is not particularly impressive as far as printout behavior is concerned. Since Agfa 10E70 emulsions are thinner than Kodak 649-F plates, the tanning action of the developer used in this process probably is not as effective as could be hoped for with thicker emulsions. Although the process shows a 31% decrease in transparency over a period of ten weeks indicating that the printout effect is a problem in this process, it was found that sodium bisulfite is a useful chemical in curtailment of the printout effect.

The Modified Developer Process

The third process studied was that of Hariharan, Kaushik, and Ramanathan. This process, which has as its special property a modified developer, will be called in this paper The Modified Developer Process. This process is a result of modifications of The Kodak R-10 Bleach Process which was first used by Altman and later by Russo and Sottini, McMahon and Franklin, Upatnieks and Leonard, and McMahon and Maloney. The initial R-10 Bleach Process utilized sodium chloride to change the final developed silver image into a silver chloride complex; however, McMahon and Franklin as well as Upatnieks and Leonard reported that R-10 Bleaches belong to a class
of printout enhancing materials. It was left to McMahon and Maloney\textsuperscript{66} to show with qualitative data that the stability against printout is essentially determined by the silver halide of which the image is formed, silver chloride being the poorest, silver bromide being somewhat better, silver iodide being the best, exhibiting a high resistance to printout darkening. McMahon and Maloney\textsuperscript{67} thus modified The Kodak R-10 Bleach Process to incorporate a potassium iodide solution in order to change the final image into a silver iodide.

The modified process worked fine with thin emulsion Agfa materials but poor results as far as image formation was concerned were obtained when the process was used on thicker Kodak 649-F plates. Hariharan and Ramanathan\textsuperscript{68} theorized that since silver iodide has a relatively high solubility in solutions of potassium iodide the solvent action of potassium iodide could result in etching of the halide image and loss of the high spatial frequency interference pattern inherent in the hologram. By lowering the concentration of potassium iodide in the bleach bath, the etching should be reduced. The Kodak R-10 Bleach was modified so that 2 grams potassium iodide per 12 liters of water were used instead of 128 grams potassium iodide per 12 liters of water, resulting in better holographic images and negligible levels of staining as compared to the higher concentration of potassium iodide.
Up to this point the process had been a direct bleaching process; the emulsion being developed, fixed, and then bleached. By accident, Hariharan, Ramanathan, and Kaushik treated an unfixed hologram in a dichromate bleach containing potassium iodide and obtained a remarkably good holographic image. Such a treatment should convert the developed silver grains into sites of silver iodide and result in a very weak phase image because of the small refractive index difference between silver bromide \((n = 2.25)\) and silver iodide \((n = 2.21)\). Reasons cited for this phenomenon include dissolution of the unexposed silver halide grains by the bleach bath as well as oxidation of the silver image by the bleach to \(Ag^+\) resulting in the unexposed emulsion grains growing slightly larger forming an intensified phase image. They tried different concentrations of potassium iodide in the bleach bath and found 2 grams of potassium iodide per 20 liters water gave optimum results in diffraction efficiency and signal to noise ratio of the holographic image. In the same paper it was reported that the bleach of ammonium dichromate used in The Kodak R-10 Bleach Process yielded poorer overall results than using potassium dichromate as the bleaching agent. Although no qualitative data were given, they reported that the stability against printout was almost as good as silver iodide phase holograms produced by bleaching a silver image by conventional
means and much better than silver bromide phase holograms.

Further work was done by Hariharan, Kaushik, and Ramanathan where they pointed out that the scattered optical noise inherent in bleached holograms is proportional to the square of the volume of the transparent grains representing the image and also learned experimentally that the maximum values of diffraction efficiency are obtained when only a small fraction of the available silver halide in the emulsion is used. Combination of these facts means that a controlled etching of the emulsion grains in a solution of a suitable silver halide solvent to reduce their size will yield a hologram with very low optical noise and a very high diffraction efficiency. After extensive testing the same group added 0.5 grams of sodium thiosulfate to the developer to act as the etching agent. The holographic images were reported to have a significant increase in signal to noise ratio (roughly 60 to 1 which is comparable to unbleached holograms), without a decrease in the diffraction efficiency. To date this is the final modification, and this process can be described as a simple negative phase image process capable of producing holographic images of reported high diffraction efficiency and low optical noise. The essential processing steps of The Modified Developer Process are given in Table VI.

The Modified Developer Process was by far the simplest process of the ones investigated in this paper. The
The Essential Processing Steps of
The Modified Developer Process

| Step 1 | Develop in Kodak D-19 and Sodium Thiosulfate |
| Step 2 | Bleach in Potassium Dichromate and Potassium Iodide |

brightness and resolution of the holographic image were both very good, although no qualitative data were taken.

The effects of printout darkening were studied in a much more qualitative manner. The Modified Developer Process was further modified in this investigation by the omission or substitution of a certain processing step to better understand how each step changes the printout resistance of the emulsion. The first variation of The Modified Developer Process was the replacement of the modified developer with D-19. The second variation was the replacement of the modified developer with D-76. The third variation was the omission of potassium iodide from the bleach bath solution.

Figures 14-16 illustrate the transparency response of the bleached emulsions to the alterations of The Modified Developer Process while Table VII gives the final absolute and normalized transparencies of these alterations.
Figure 14. Time Variation of Absolute and Normalized Transparency of Holograms processed with The Modified Developer Process (MDP) and processed with D-19 substituted as the developer in The Modified Developer Process.
Figure 15. Time Variation of Absolute and Normalized Transparency of Holograms processed with The Modified Developer Process (MDP) substituting D-19 and D-76 as developers

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Figure 16. Time Variation of Absolute and Normalized Transparency of Holograms processed with The Modified Developer Process (MDP) substituting D-19 as the developer and substituting D-19 as the developer along with omission of potassium iodide from the bleach bath.
Table VII

Final Absolute and Normalized Transparencies of Holograms Processed with The Modified Developer Process and Processed with the Three Modifications Performed on The Modified Developer Process

<table>
<thead>
<tr>
<th></th>
<th>Absolute Transparency</th>
<th>Normalized Transparency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified Developer Process</td>
<td>54%</td>
<td>72%</td>
</tr>
<tr>
<td>Developed with D-19</td>
<td>41%</td>
<td>63%</td>
</tr>
<tr>
<td>Developed with D-76</td>
<td>43%</td>
<td>70%</td>
</tr>
<tr>
<td>Without Potassium Iodide</td>
<td>44%</td>
<td>66%</td>
</tr>
</tbody>
</table>

The absolute and normalized transparency of holograms processed with The Modified Developer Process were higher than those of any of the alterations. Developing with D-76 yields holograms which are slightly more transparent and more resistive to printout than holograms developed with D-19. Printout was less severe when potassium iodide was omitted, which is a fact difficult to explain. Perhaps the small concentration of potassium iodide in the bleach bath does not work as effectively on Agfa emulsions, since The Modified Developer Process was developed to use on Kodak 649-F emulsions which are several times thicker. Although holograms processed with The Modified Developer Process had transparencies and printout resistance superior to any of the alterations made in this investigation,
the printout behavior of this process is still quite a problem. The quality of the holographic images was slightly superior when processed using The Modified Developer Process in comparison to any of the alterations, although no qualitative data were taken.

The Modified Reversal Bleach Process

The fourth process investigated was The Modified Reversal Bleach Process initiated by Hariharan\textsuperscript{71} and finalized by Hariharan and Ramanathan\textsuperscript{72}. This process can be described as a true reversal bleach system.

Hariharan and Ramanathan\textsuperscript{73} further explored methods of converting silver bromide phase holograms to silver iodide phase holograms. The problem was to introduce the iodide ion in a form which would not result in formation of soluble complexes in the emulsion. Since quaternary ammonium iodides behave like strong electrolytes when in solution, Ag\textsuperscript{+} would be readily converted to silver iodide and the solubility of silver iodide in the solution would be small. They concluded that holograms treated in a 0.2\% solution of tetramethylammonium iodide\textsuperscript{74} resulted in excellent holograms with low optical noise, high diffraction efficiency, and good resistance to printout. The essential processing steps of The Modified Reversal Bleach Process are given in Table VIII.

The Modified Reversal Bleach Process produced holo-
<table>
<thead>
<tr>
<th>Step</th>
<th>Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Develop in Kodak D-19</td>
</tr>
<tr>
<td>2</td>
<td>Re-expose uniformly to White Light</td>
</tr>
<tr>
<td>3</td>
<td>Redevelop in Kodak D-19</td>
</tr>
<tr>
<td>4</td>
<td>Bleach in Potassium Dichromate</td>
</tr>
<tr>
<td>5</td>
<td>Clear in Tetramethylammonium Iodide</td>
</tr>
</tbody>
</table>

grams with optical noise lower than any other process tested in this paper and diffraction efficiencies as good as with any process tested, although no qualitative data were taken. The re-exposure to uniform light was found to be quite critical as to exposure intensity and time. With Agfa 10E70 film the re-exposure was done by a 25 watt light bulb at a distance of 4 feet for a duration of 0.5 seconds.

The effects of printout were studied in a much more qualitative manner. The Modified Reversal Bleach Process was further altered in this investigation by the omission or substitution of a certain processing step to better understand how each step changes the printout resistance of the emulsion. The first variation of The Modified
Reversal Bleach Process was the replacement of D-19 with D-76 as the developer. The second variation was the substitution of sodium bisulfite for tetramethylammonium iodide as the clearer. The third modification was the omission of the clearer.

Figures 17-19 illustrate the transparency response of the bleached emulsions to the alterations of The Modified Reversal Bleach Process while Table IX gives the final absolute and normalized transparencies of these alterations.

Table IX

<table>
<thead>
<tr>
<th></th>
<th>Absolute Transparency</th>
<th>Normalized Transparency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified Reversal Bleach Process</td>
<td>46%</td>
<td>82%</td>
</tr>
<tr>
<td>Developed with D-76</td>
<td>45%</td>
<td>84%</td>
</tr>
<tr>
<td>Cleared with Sodium Bisulfite</td>
<td>49%</td>
<td>74%</td>
</tr>
<tr>
<td>Without Clearer</td>
<td>43%</td>
<td>71%</td>
</tr>
</tbody>
</table>

The Modified Reversal Bleach Process yields holograms which hold 82% of their initial transparencies which classifies this process as the best yet investigated for
Figure 17. Time Variation of Absolute and Normalized Transparency of Holograms processed with The Modified Reversal Bleach Process (MRBP) and processed with D-76 substituted as the developer in The Modified Reversal Bleach Process.
Figure 18. Time Variation of Absolute and Normalized Transparency of Holograms processed with The Modified Reversal Bleach Process (MRBP) and processed with Sodium Bisulfite as the clearer in The Modified Reversal Bleach Process.
Figure 19. Time Variation of Absolute and Normalized Transparency of Holograms processed with The Modified Reversal Bleach Process (MRBP) and processed without the clearer in The Modified Reversal Bleach Process.
resisting printout. Substituting D-76 as the developer changed the transparency response very little. Clearing with sodium bisulfite produced holograms which were more transparent yet more susceptible to printout than holograms cleared in tetramethylammonium iodide. Processed holograms which were not cleared were slightly less transparent and severely more susceptible to printout than holograms cleared either with sodium bisulfite or tetramethylammonium iodide. No significant differences could be seen in the holographic images processed by the different alterations although no qualitative data were taken.

The Agfa Process

The final process investigated was that recommended by Agfa-Gevaert to produce phase holograms. The bleach utilized is potassium dichromate, the same used by three of the processes investigated in this paper.

The unusual thing about The Agfa Process is that the desensitization bath incorporates phenosafranine as the active material. Phenosafranine is a well known red dye and was found to be a powerful photographic desensitizer by Luppo-Cramer who showed that adding it to a developer in one part per twenty thousand enabled the photographic plate to be examined in a bright light after only a one minute development and also that adding it to a prebath enabled development to be carried out in the presence of
a considerable amount of light. Chang and George\textsuperscript{78} reported soaking plates in a solution of safranine aconc, a material similar in structure to phenosafranine, and reported that plates turned darker at a slower rate when treated with this material. They conjecture that such dyes cause the gelatin to absorb strongly in the blue acting as a blue filter blocking light off from the silver halide grains. The essential processing steps of The Agfa Process are given in Table X.

Table X
The Essential Processing Steps of The Agfa Process

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
<td>Develop in Kodak D-19</td>
</tr>
<tr>
<td>Step 2</td>
<td>Bleach in Potassium Dichromate</td>
</tr>
<tr>
<td>Step 3</td>
<td>Clear in Sodium Sulfite and Sodium Hydroxide</td>
</tr>
<tr>
<td>Step 4</td>
<td>Desensitize in Phenosafranine</td>
</tr>
</tbody>
</table>

The Agfa Process produced holograms which yielded holographic images which were good as far as brightness and resolution are concerned although no qualitative data were taken.

The effects of printout darkening were studied in a much more qualitative manner. The Agfa Process was fur-
ther modified in this investigation by the omission or substitution of a certain processing step to better understand how each step changes the printout resistance of the emulsion. The first variation of The Agfa Process was the replacement of D-76 for D-19 as the developer. The second variation was the omission of phenosafranine from the desensitization bath. The third variation was the omission of the entire desensitization bath. The fourth variation was the omission of the clearer.

Figures 20-22 illustrate the transparency response of the bleached emulsions to the alterations of The Agfa Process while Table XI gives the final absolute and normalized transparencies of these alterations.

Table XI

Final Absolute and Normalized Transparencies of Holograms Processed with The Agfa Process and Processed with the Four Modifications Performed on The Agfa Process

<table>
<thead>
<tr>
<th></th>
<th>Absolute Transparency</th>
<th>Normalized Transparency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agfa Process</td>
<td>53%</td>
<td>32%</td>
</tr>
<tr>
<td>Developed with D-76</td>
<td>57%</td>
<td>92%</td>
</tr>
<tr>
<td>Without Phenosafranine in the Desensitizer</td>
<td>45%</td>
<td>67%</td>
</tr>
<tr>
<td>Without Desensitizer</td>
<td>46%</td>
<td>70%</td>
</tr>
<tr>
<td>Without Clearer</td>
<td>55%</td>
<td>90%</td>
</tr>
</tbody>
</table>

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Figure 20. Time Variation of Absolute and Normalized Transparency of Holograms processed with The Agfa Process (AP) and processed with D-76 substituted as the developer in The Agfa Process.
Figure 21. Time Variation of Absolute and Normalized Transparency of Holograms processed with the Agfa Process (AP) and processed without the clearer in The Agfa Process.
Figure 22. Time Variation of Absolute and Normalized Transparency of Holograms processed with The Agfa Process (AP), processed without phenosafranine in the desensitizer of The Agfa Process, and processed without the desensitizer in The Agfa Process.
Holograms developed in D-76 had surprisingly higher transparencies and higher resistance to printout than holograms developed in D-19. Holograms processed without phenosafranine in the desensitization bath exhibited the lowest transparency levels and lowest resistance to printout of any alteration indicating that phenosafranine is a very powerful substance in producing holograms which have high transparency and high resistance to printout. Holograms processed without the desensitization bath have transparency responses quite similar to holograms processed without just phenosafranine. These curves therefore justify the statement that phenosafranine is the only active chemical in the desensitization bath optimizing holographic transparency responses. Holograms processed without the clearer were more transparent and less susceptible to printout than holograms processed with The Agfa Process, indicating that the chemicals sodium hydroxide and sodium sulfite in the clearer do little clearing, but do sensitize the emulsion slightly to printout darkening. No significant differences could be seen in the holographic images processed by the different alterations, although no qualitative data were taken. Removal of the clearing bath, developing in D-76, and using phenosafranine as a desensitizer yields holograms which hold about 90% of their initial transparency, by far the best process investigated for resisting printout.
CHAPTER VI

ATTEMPTS TO IMPROVE HOLOGRAPHIC IMAGES

In addition to testing the five processes described previously, other attempts were made to develop bleached holographic images of better quality as well as trying to understand more fully the printout phenomenon.

Printout Resulting from Variable Light Intensities

The first experiment designed was to try to correlate the printout effect as a function of light intensity incident upon the processed hologram. Five holograms were processed using The Modified Developer Process and five processed using The Modified Reversal Bleach Process. A hologram from each process was placed at distances of 8, 4, 2, 1, and 0.5 feet from a 75 watt incandescent light bulb. The holograms were illuminated twenty-four hours a day and monitored on the Bausch and Lomb micro-photometer every three days in the same manner as described previously. Figures 23 and 24 show the transparency and printout behavior of each hologram as a function of time.

For The Modified Developer Process the final transparency levels are as follows: 8 feet, 82%; 4 feet, 80%; 2 feet, 76%; 1 foot, 64%; 0.5 feet, 63%. The same values for The Modified Reversal Bleach Process are as follows: 8 feet, 89%; 4 feet, 85%; 2 feet, 79%; 1 foot, 65%; 0.5
Figure 23: Time Variation of Absolute and Normalized Transparency of Holograms processed with The Modified Developer Process arranged at various distances from a printout inducing light source.

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Figure 24. Time Variation of Absolute and Normalized Transparency of Holograms processed with The Modified Reversal Bleach Process arranged at various distances from a printout inducing light source.
feet, 70%. Although the relationship is not simple, it does appear that the printout effect is more severe as the light intensity increases.

Printout Resulting from Wavelength Variation of Light

The second experiment was designed to study the printout effect as a function of the wavelength of light striking the emulsion. Six holograms were processed using The Modified Reversal Bleach Process and each was placed behind a filter which allowed only monochromatic light to strike it. The light source was an incandescent light bulb and the filters were arranged so that equal intensities of monochromatic light struck each hologram. The transparency of each hologram was monitored by the Bausch and Lomb microphotometer as described previously. Figure 25 shows the transparency and printout behavior of each hologram as a function of time.

After a thirty day period of time the following transparency percentages of the original transparency were recorded: yellow filter, 73%; green filter, 79%; blue filter, 80%; blue-green filter, 84%; opaque filter (no light striking the emulsion), 92%; red filter, 95%.

Although the results are inconclusive as far as finding a working correlation between wavelength and printout darkening, they do show a couple of notable features: 1) holograms tend to darken even in the dark,
Figure 25. Time Variation of Absolute and Normalized Transparency of Holograms processed with The Modified Reversal Bleach Process arranged with different filters placed in front of a printout inducing light.
2) putting holograms in an environment where only red filters are used for illumination will insure a long life for holograms with respect to printout darkening.

Printout Resulting from Ultrasonic Agitation

In attempting to develop bleached holographic images of better resolution and brightness, the idea of trying to produce finer grained emulsions was explored. The reason for producing an emulsion with smaller grain size would be an increased probability in higher resolution of the holographic image.

In a typical ultrasonic cleaner a drop of mercury after a short period of time will be completely disso­ciated throughout the containing bath of water. If an unexposed photographic emulsion was placed in an ultrasonic cleaner, it might be reasonable to expect that the emulsion grains would be broken down into smaller par­ticles. Unexposed Agfa 10E70 film was processed in a Bendix Sonic Energy Cleaner\textsuperscript{79} for a five minute period of time. The film was then allowed to air dry for three days. Holograms were then processed in one of three ways: 1) developed in D-19, then bleached in potassium di­chromate; 2) developed in D-19, bleached in potassium dichromate, then desensitized in phenosafranine; 3) developed in D-19, re-exposed to uniform light, re­developed in D-19 (reversal bleached), then desensitized.
in phenosaframine. Figure 26 shows the transparency and printout behavior of each modification as a function of time.

Holograms processed by methods two and three produced very weak holographic images while the images produced in method number one were only fair. The transparency of holograms processed with the ultrasonic unit went from 42% to 52%. Holograms processed by method number one held only 63% of their initial transparency after a thirty day period of time while method number two holograms eventually held 98% of the initial transparency after recovery from 83% after three days and method number three holograms eventually held 94% of the initial transparency after recovery from 81% after a three day period. Although holograms processed using the ultrasonic unit have images which range from fair to poor, their printout resistance is very high when suitably processed.

Ultrasonic Agitation Effect upon Wavelength Sensitivity

The Bendix Sonic Energy Cleaner was also used in studying the effects of processing Kodak S.A.-3 spectrographic plates through the cleaner with regard to possible increased resolution of spectral lines. An S.A.-3 plate was placed in the ultrasonic cleaner for five minutes, let dry for five days, and then positioned in a Hilger Medium Quartz Spectrograph. A rotating step sector was

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Figure 26. Time Variation of Absolute and Normalized Transparency of Holograms processed with different modifications after agitation of the unexposed film in an ultrasonic cleaner.
positioned in front of the spectroscopic slit and twin iron electrodes were burned by an arc source for a forty second duration. The plate was then developed in D-19 for five minutes, put in a stop bath for fifteen seconds, and finally fixed for three minutes in Kodak Rapid Fixer. Another S.A.-3 plate was processed in the exact same manner except that this plate was not agitated in the ultrasonic cleaner. After comparison of the dried plates no resolution difference could be seen in spectral lines; however, the ultrasonically agitated plate appeared to have slightly darker spectral lines. An H & D curve was plotted from the unagitated plate and the darkneses of spectral lines were compared at intervals of about 250 angstroms.

The ultrasonically agitated plate had spectral lines consistently darker than those on the unagitated plate, running from equal intensities to 1.4 times as dark. The significant point about the study is the fact that in the region of 4750 angstroms to 5300 angstroms the spectral lines were 1.3 to 1.4 times darker on the ultrasonically agitated plate, a fact hard to explain away by processing chemical changes, slight differences in spectroscopic processing, or initial differences between the plates. Figure 27 shows the ratio of spectral line darkneses as a function of wavelength.
Effect of Toners on Brightness and Resolution

A study of toners was also made in the hope that out of this branch of photographic processing a method could be found to produce holographic images of superior quality.

Normally processed amplitude holograms were toned in one of four toner solutions: 1) Hypo Alum Toner (Agfa 222), 2) Iron Blue Toner (Agfa 241), 3) Sulfide Toner (Kodak T-10), 4) Uranium Toner (Kodak T-9). Although no qualitative data were taken, the holographic image brightness and resolution were not improved with any of the toners but actually decreased in cases. A conclusion must be reached that toning of a hologram produces no improvement of the holographic image.
Liquid Gates and Holographic Resolution

Several articles in the literature\(^{82-88}\) have mentioned using liquid gates to try to improve the resolution of holographic images. Ideally this liquid gate would match the index of refraction of the gelatin and fill in any scattering centers produced by the formation of a relief image on the emulsion surface or by pock marks in the emulsion where metallic silver sites have been vacated by bleaching.

Seven materials were investigated as to their ability to increase holographic image resolution when used as liquid gates on holograms produced on Agfa 10E70 films. The materials are as follows: 1) Xylene\(^{89}\), 2) Methyl Benzoate\(^{90}\), 3) Chlorobenzene\(^{91}\), 4) Bromoethane\(^{92}\), 5) p-Chlorotoulene\(^{93}\), 6) 1,2-Dibromopropane\(^{94}\), 7) 1,3-Dibromopropane\(^{95}\). All of these materials have refractive index of approximately 1.50, the same as photographic gelatin.

The liquid gates were formed by gluing with rubber cement a round washer made of bone onto the emulsion surface, filling the washer with the material, then cementing a thin glass slide onto the top of the washer.

Although no qualitative data were taken, holographic image resolution did not change with any of the materials tested except xylene, where the image resolution was severely decreased. The probable formation of very small...
relief images on the relatively thin Agfa 10E70 emulsion might be one possibility as to why there is no resolution improvement.
CHAPTER VII

SELECTING AN OPTIMUM HOLOGRAPHIC PROCESS

After the investigations were performed on the five processes described previously in Chapter IV, it was noted that combining the good aspects of some processes could possibly result in a general all around better process for producing phase holograms. Holograms were processed in one of the following twelve ways: 1) developed, then bleached; 2) developed, bleached, then processed in tetramethylammonium iodide; 3) developed, bleached, processed in tetramethylammonium iodide, then processed in pheno- safranine; 4) prehardened, developed, bleached, processed in tetramethylammonium iodide, then processed in pheno- safranine; 5) developed, then reversal bleached; 6) developed, reversal bleached, then processed in phenosaf- ranine; 7) developed, reversal bleached, then processed in tetramethylammonium iodide; 8) developed, reversal bleached, processed in tetramethylammonium iodide, then processed in phenosafranine; 9) developed in D-19, then bleached with The Modified Stanford Process bleach; 10) developed in D-19, fixed, then bleached with The Modified Stanford Process bleach; 11) developed in D-19, bleached with The Modified Stanford Process bleach, then processed in phenosafranine; 12) developed in D-19, fixed, bleached with The Modified Stanford Process bleach, then processed
in phenosafranine. Unless otherwise indicated, the developer used was the modified developer investigated in The Modified Developer Process and unless otherwise indicated the bleaching agent was potassium dichromate. These twelve modifications are summarized in Table XII.

Figures 28-33 illustrate the transparency response of the bleached emulsions to the alterations described previously while Table XIII gives the final absolute and normalized transparencies of these alterations.

Holograms processed by methods number one and two both yielded final transparency levels of 42%, which was 75% of the initial transparency for method number one as compared to 79% of the initial transparency for method number two holograms. This indicates that processing in tetramethylammonium iodide does help in resisting printout by about 4% without changing the opacity of the hologram. The final transparency of method number three holograms was 44%, which was 90% of the original transparency. This shows that phenosafranine increased the normalized transparency by 11% over holograms processed without it, even increasing the final transparency in doing so. The final transparency of method number four holograms was 47%, which was 87% of the initial transparency. It seems that pre-hardening increases the transparency somewhat but also lowers the printout resistance slightly. The final transparency of method number five holograms was 46%, which was...
Table XII
Summary of The Western Michigan University Modifications

<table>
<thead>
<tr>
<th>MODIFICATION</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Developed, then bleached</td>
</tr>
<tr>
<td>2</td>
<td>Developed, bleached, then cleared</td>
</tr>
<tr>
<td>3</td>
<td>Developed, bleached, cleared, then desensitized</td>
</tr>
<tr>
<td>4</td>
<td>Prehardened, developed, bleached, cleared, then desensitized</td>
</tr>
<tr>
<td>5</td>
<td>Developed, then reversal bleached</td>
</tr>
<tr>
<td>6</td>
<td>Developed, reversal bleached, then desensitized</td>
</tr>
<tr>
<td>7</td>
<td>Developed, reversal bleached, then cleared</td>
</tr>
<tr>
<td>8</td>
<td>Developed, reversal bleached, cleared, then desensitized</td>
</tr>
<tr>
<td>9</td>
<td>Developed with D-19, then bleached with CuBr$_2$ + FeCl$_3$</td>
</tr>
<tr>
<td>10</td>
<td>Developed with D-19, fixed, then bleached with CuBr$_2$ + FeCl$_3$</td>
</tr>
<tr>
<td>11</td>
<td>Developed with D-19, bleached with CuBr$_2$ + FeCl$_3$, then desensitized</td>
</tr>
<tr>
<td>12</td>
<td>Developed with D-19, fixed, bleached with CuBr$_2$ + FeCl$_3$, then desensitized</td>
</tr>
</tbody>
</table>

Unless otherwise indicated the developer used was The Modified Developer investigated in chapter IV, and the bleaching agent was potassium dichromate. The clearer refers to tetramethylammonium iodide and the desensitizer refers to phenosafranine.
Figure 28. Time Variation of Absolute and Normalized Transparency of Holograms processed with Western Michigan University Modifications One and Two
Figure 29. Time Variation of Absolute and Normalized Transparency of Holograms processed with Western Michigan University Modifications Two and Three
Figure 30. Time Variation of Absolute and Normalized Transparency of Holograms processed with Western Michigan University Modifications Three and Four
Figure 31. Time Variation of Absolute and Normalized Transparency of Holograms processed with Western Michigan University Modifications Five, Six, and Seven
Figure 32. Time Variation of Absolute and Normalized Transparency of Holograms processed with Western Michigan University Modifications Six, Seven, and Eight
Figure 33. Time Variation of Absolute and Normalized Transparency of Holograms processed with Western Michigan University Modifications Nine, Ten, Eleven, and Twelve
Table XIII

Final Absolute and Normalized Transparencies of Holograms Processed with The Twelve Western Michigan University Modifications

<table>
<thead>
<tr>
<th>Modification Number</th>
<th>Absolute Transparency</th>
<th>Normalized Transparency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>42%</td>
<td>75%</td>
</tr>
<tr>
<td>2</td>
<td>42%</td>
<td>79%</td>
</tr>
<tr>
<td>3</td>
<td>44%</td>
<td>90%</td>
</tr>
<tr>
<td>4</td>
<td>47%</td>
<td>87%</td>
</tr>
<tr>
<td>5</td>
<td>46%</td>
<td>71%</td>
</tr>
<tr>
<td>6</td>
<td>63%</td>
<td>90%</td>
</tr>
<tr>
<td>7</td>
<td>63%</td>
<td>101%</td>
</tr>
<tr>
<td>8</td>
<td>62%</td>
<td>105%</td>
</tr>
<tr>
<td>9</td>
<td>52%</td>
<td>91%</td>
</tr>
<tr>
<td>10</td>
<td>66%</td>
<td>96%</td>
</tr>
<tr>
<td>11</td>
<td>53%</td>
<td>114%</td>
</tr>
<tr>
<td>12</td>
<td>69%</td>
<td>107%</td>
</tr>
</tbody>
</table>

only 71% of the initial transparency. The final transparency of method number six holograms was 63%, which was 90% of the initial transparency, indicating that pheno-safranine increased transparency by 17% and printout resistance by 19%. The final transparency of method number seven holograms was 63%, which was 101% of the initial transparency. The transparency level dropped to 96% of
the original after three days but quickly recovered to the final value. Tetramethylammonium iodide thus increased the transparency by 16% and the resistance to printout by 30%. The final transparency of method number eight holograms was 62% which was 105% of the initial transparency, this level never dropping to less than 100% and never going above 106%. It appears that with reversal bleached holograms tetramethylammonium iodide has a greater resistance to printout than does pheno-safranine, just the opposite of what occurs with holograms processed with a negative phase image process. The final transparency of method number nine holograms was 52%, which was 91% of the original transparency. However, this normalized value was only 66% after three days, recovering slowly as time progressed. The final transparency of method number ten holograms was 66%, which was 96% of the original transparency. This normalized value dropped to 89% after three days but slowly recovered to the present value. Since this recovery phenomenon occurs both with fixed and unfixed holograms, the recovery must be linked with the bleach bath used in The Modified Stanford Process. The final transparency of method number eleven holograms was 53%, which was 114% of the initial value, the lowest normalized value being 99% after three days. The final transparency of method number twelve holograms was 69%, which was 107% of the initial value, the lowest normalized
value being 99% after six days. It appears that phenosafranine staves off the initial severe degradation inherent to holograms bleached with The Modified Stanford Process bleach and then they recover above the initial transparency by some mechanism still unclear, but very possibly connected to the materials used in the bleach bath.

Holograms processed with methods number eight and twelve were the only ones which showed excellent resistance to printout, high transparency, and good emulsion stability. Therefore, further trials were done on holograms bleached in one of three manners: 1) developed in The Modified Developer Process developer, reversal bleached in potassium dichromate, cleared in tetramethylammonium iodide, then desensitized in phenosafranine; 2) developed in D-19, fixed, bleached in ferric chloride and cupric bromide, then cleared in tetramethylammonium iodide; 3) developed in D-19, fixed, bleached in ferric chloride and cupric bromide, then desensitized in phenosafranine. Figure 34 shows the transparency and printout behavior of each modification as a function of time. The above modifications are identified in Figure 34 as 4A, 12A, and 12B respectively.

The final transparency of modification 4A holograms was 66%, which was 103% of the initial transparency. Never did this normalized value go below 100% or above
Figure 34. Time Variation of Absolute and Normalized Transparency of Holograms processed with Western Michigan University Modifications 4A, 12A, and 12B
104%. This indicates that processing with this modification produces holograms which have very stable compounds residing in the emulsion. The final transparency of modifications 12A and 12B was 47% and 61% respectively which was 123% and 117% of their initial transparency. This recovery is representative of holograms bleached in cupric bromide and ferric chloride. One may question if this drastic recovery of holographic transparency degrades the image; however, no significant change could be observed visually in the holographic images which were processed in this fashion.

Western Michigan University Modifications Number 12A and 12B will be described as The Derby Process and Western Michigan University Modification Number 4A will be described as The Markham Process in Tables XIV and XV and appendices VI and VII respectively.

Table XIV
The Essential Processing Steps of The Derby Process

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
<td>Develop in Kodak D-19</td>
</tr>
<tr>
<td>Step 2</td>
<td>Fix in Kodak Rapid Fixer</td>
</tr>
<tr>
<td>Step 3</td>
<td>Bleach in Cupric Bromide and Ferric Chloride</td>
</tr>
<tr>
<td>Step 4</td>
<td>Desensitize in Phenosafranine and/or Clear in Tetramethylammonium Iodide</td>
</tr>
</tbody>
</table>
Table XV
The Essential Processing Steps of The Markham Process

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Develop in Kodak D-19 and Sodium Thiosulfate</td>
</tr>
<tr>
<td>2</td>
<td>Re-expose uniformly to white light</td>
</tr>
<tr>
<td>3</td>
<td>Redevelop in Kodak D-19 and Sodium Thiosulfate</td>
</tr>
<tr>
<td>4</td>
<td>Clear in Tetramethylammonium Iodide</td>
</tr>
<tr>
<td>5</td>
<td>Desensitize in Phenosafranine</td>
</tr>
</tbody>
</table>
CONCLUSIONS

A process has been developed which produces photographic phase holograms of high diffraction efficiency, low noise, and high resistance to printout darkening. The process was developed by combining the best qualities of some of the latest processes reported in the literature. The first innovation was the use of a modified developer which consists of a very small amount of sodium thiosulfate added to Kodak D-19. This developer slightly etches the undeveloped silver bromide particles in the emulsion making them smaller and as a result they scatter less light giving increased resolution to the holographic image. The second innovation utilizes the concept of reversal bleaching. After the initial development the entire hologram is then re-exposed to uniform white light and after a second development and bleaching of the emulsion only the grains of silver bromide shielded by the metallic silver produced by the first development remain in the emulsion. These remaining grains, called the reversed image, contain all of the information which was recorded on the emulsion prior to the first development. Due to this reversal bleaching process, the scattering of the emulsion has been cut significantly because most of the original silver bromide particles have been processed away. The third innovation was the use of tetra-
methylammonium iodide to convert the silver bromide particles remaining in the emulsion into silver iodide. Silver iodide resists printout darkening much more than does silver bromide, and tetramethylammonium iodide being a strong electrolyte in solution converts very satisfactorily the grains into silver iodide without the etching of these grains which does occur with other processes. The fourth innovation was the use of pheno­safranine to desensitize the emulsion from printout darkening. Pheno­safranine is a red dye which is thought to cause the gelatin to absorb short wavelength light. This absorption thus removes the high energy photons which apparently are more active in causing printout.

A direct bleach process using cupric bromide and ferric chloride as the bleaching agent, followed by processing in tetramethylammonium iodide and/or pheno­safranine, produces holograms which resist printout darkening but have slightly less resolution of the images than the process described previously. The advantage of this process is that it is very simple and only one of two exotic chemicals need be obtained. The process described previously involves many steps including a re-exposure which is somewhat difficult to control.

Other methods of trying to improve photographic phase holograms did not produce as good results. Holograms were toned in the hopes that higher diffraction efficien-
cies could be observed. Holograms were immersed in index of refraction matching liquids in the hopes that lower optical noise levels could be produced. Holographic film was agitated in an ultrasonic cleaner in the hopes of creating smaller grain sizes in the emulsion and gaining resolution of the holographic images. In all cases the results turned out disappointing.

After twenty seven days of constant exposure by an incandescent lamp, holograms situated at different distances from the lamp recovered significantly in transparency after the lamp was found to have burned out between twenty seven and thirty days of constant exposure. This indicated that after exposure to light, holograms recover some of their initial transparency if they are placed in darkness. A further study is suggested to determine the effects of pulsed light of different frequencies on the printout stability of bleached holograms.

Although using the ultrasonic cleaner for improving holographic image quality failed, a Kodak S.A.-3 plate agitated in the device produced slightly darker spectral lines than a plate not agitated. The lines were almost 1.5 times as dark on the red end of the spectrum. A further study is suggested to determine if agitating certain emulsions in an ultrasonic cleaner produces increased sensitivity at certain wavelengths.

In the bleached holograms of this investigation, the
phenomena of printout and subsequent partial recovery are thought to be related to the solarization processes in ordinary photography. The response of the bleached holograms to prolonged illumination is characterized by the various experimental curves shown in this paper. These curves all have similar shapes and most display a region of decreasing transparency followed by a region of increasing transparency, although the different curves show these effects in varying degrees. This transparency decline and partial recovery is represented by the typical curve of figure 35.

![Graph](image-url)

**Figure 35. Time Variation versus Absolute Transparency for a Typical Bleached Hologram**

The printout region AB illustrates a period of time during which the sustained illumination on the hologram is causing an emulsion darkening. The increased density of the emulsion is thought to be caused by the photolytic generation of atomic metallic silver both within the silver
halide crystals and on their surfaces. The progressive darkening continues until it bottoms out (at B) due to a competing re-brominization process.

The transparency recovery region BC may be explained by the gradual decrease in the ratio of the printout silver on the halide grain surface compared to printout silver in the grain interior. The halogen is usually liberated at the grain surface where it can unite with the surface silver, while the grain itself (via hole transport mechanism) tends to protect the internal printout silver. The decrease of printout silver from the grain surface and the increase of interior printout silver results in an overall effect of increased transparency of the hologram. The decrease in absorption is related to an effective decrease in the absorbing area of the printout silver.

The research of this paper has generated two significant modifications on photographic phase hologram processing. These have been identified in Tables XIV and XV and described in detail in appendices VI and VII as The Derby Process and The Markham Process respectively. These processes are particularly valuable in producing photographic phase holograms with high transparency levels which experience less printout than by any other known method.
APPENDIX I

PROCESSING STEPS FOR
THE MODIFIED STANFORD PROCESS

3 Min. 1) Preharden in Kodak Prehardener SH-5
5 Min. 2) Develop in Kodak D-19
15 Sec. 3) Stop Bath
3 Min. 4) Fix in Kodak Rapid Fixer
10 Min. 5) Rinse in Distilled Water
7 Min. 6) Bleach
30 Sec. 7) Rinse in Distilled Water
1 Min. 8) Clear and Desensitize
10 Min. 9) Rinse in Distilled Water
5 Min. 10) Dry in 50% Methanol
3 Min. 11) Dry in 100% Methanol
12) Dry Slowly at Room Temperature

BLEACH
Ferrous Chloride .............. 25 grams
Cuprous Bromide ............. 25 grams
Concentrated Sulfuric Acid .. 15 milliliters
Distilled Water .............. 500 milliliters

CLEAR AND DESENSITIZE
Solution A
Potassium Permanganate ....... 5 grams
Distilled Water .............. 1 liter

Solution B
Potassium Bromide ............ 50 grams
Concentrated Sulfuric Acid .. 10 milliliters
Distilled Water .............. 1 liter
( 1 part of A to 10 parts of B )
APPENDIX II

PROCESSING STEPS FOR
THE KODAK REVERSAL BLEACH SYSTEM

5 Min. 1) Develop in Kodak Special Developer SD-48
15 Sec. 2) Stop Bath
1 Min. 3) Rinse in Running Water
3 Min. 4) Bleach
5 Min. 5) Rinse in Running Water
1 Min. 6) Stain Remover
1 Min. 7) Clearer
8 Min. 8) Rinse in Running Water
5 Min. 9) Dry in 50% Methanol
10) Wash Twice in Isopropyl Alcohol

KODAK SPECIAL DEVELOPER SD-48

Solution A
Sodium Sulfite ................ 8 grams
Pyrocatechol .................. 40 grams
Sodium Sulfate ............... 100 grams
Distilled Water ................ 1 liter

Solution B
Sodium Hydroxide ............. 20 grams
Sodium Sulfate ............... 100 grams
Distilled Water ................ 1 liter

( 1 part of A to 1 part of B just before using )

BLEACH
Potassium Dichromate .......... 9.5 grams
Concentrated Sulfuric Acid .... 12 milliliters
Distilled Water ................ 1 liter

STAIN REMOVER
Potassium Permanganate ....... 2.5 grams
Concentrated Sulfuric Acid .... 8 milliliters
Distilled Water ................ 1 liter

CLEARER
Sodium Bisulfite .............. 10 grams
Distilled Water ................ 1 liter
APPENDIX III

PROCESSING STEPS FOR
THE MODIFIED DEVELOPER PROCESS

5 Min. 1) Develop in The Modified Developer
3 Min. 2) Rinse in Distilled Water
5 Min. 3) Bleach
6 Min. 4) Rinse in Distilled Water

THE MODIFIED DEVELOPER
Kodak D-19 ................ 1 liter
Sodium Thiosulphate ......... 0.5 gram

BLEACH
Solution A
Potassium Dichromate .......... 8 grams
Concentrated Sulfuric Acid . . . 10 milliliters
Distilled Water .............. 1 liter

Solution B
Potassium Iodide .............. 2 grams
Distilled Water .............. 1 liter
( 1 part of A to 1 part of B to 8 parts of distilled water just before using )
APPENDIX IV

PROCESSING STEPS FOR THE MODIFIED REVERSAL BLEACH PROCESS

5 Min. 1) Develop in Kodak D-19
90 Sec. 2) Rinse in Distilled Water
3) Re-expose Uniformly to White Light
   (Approximately 15 sec. to a 15-W bulb
   at 1 meter for Kodak 649-P plates and
   approximately .5 sec. to a 25-W bulb
   at 4 feet for Agfa-Gevaert 10870 film)

5 Min. 4) Redevelop in Kodak D-19
3 Min. 5) Rinse in Distilled Water
12 Min. 6) Bleach
3 Min. 7) Rinse in Distilled Water
5 Min. 8) Clear
9 Min. 9) Rinse in Distilled Water

**BLEACH**

Potassium Dichromate ... 0.4 gram
Concentrated Sulfuric Acid ... 0.5 milliliter
Distilled Water ....... 1 liter

**CLEARER**

Tetramethylammonium Iodide ... 2 grams
Distilled Water ....... 1 liter
APPENDIX V

PROCESSING STEPS FOR THE AGFA PROCESS

5 Min.  1) Develop in Kodak D-19
2 Min.  2) Stop Bath
5 Min.  3) Rinse in Distilled Water
2 Min.  4) Bleach
5 Min.  5) Rinse in Distilled Water
1 Min.  6) Clear
5 Min.  7) Rinse in Distilled Water
10 Min. 8) Desensitize

9) Rinse Briefly in Ethyl Alcohol and Air Dry

BLEACH
Potassium Dichromate ........... 5 grams
Concentrated Sulfuric Acid . . . 5 milliliters
Distilled Water ................. 1 liter

CLEARER
Sodium Sulphite ................ 50 grams
Sodium Hydroxide ......... 1 gram
Distilled Water ................. 1 liter

DESENSITIZER
Ethyl Alcohol .................. 88 percent
Distilled Water ............... 10 percent
Glycerol 2 percent
Potassium Bromide ............. 120 milligrams/liter
Phenosafranine ............... 200 milligrams/liter
# APPENDIX VI

## PROCESSING STEPS FOR THE DERBY PROCESS

<table>
<thead>
<tr>
<th>Time</th>
<th>Step</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 Min.</td>
<td>1) Develop in Kodak D-19</td>
</tr>
<tr>
<td>15 Sec.</td>
<td>2) Stop Bath</td>
</tr>
<tr>
<td>3 Min.</td>
<td>3) Fix in Kodak Rapid Fixer</td>
</tr>
<tr>
<td>5 Min.</td>
<td>4) Rinse in Distilled Water</td>
</tr>
<tr>
<td>7 Min.</td>
<td>5) Bleach</td>
</tr>
<tr>
<td>5 Min.</td>
<td>6) Rinse in Distilled Water</td>
</tr>
<tr>
<td>5 Min.</td>
<td>7) Clear</td>
</tr>
<tr>
<td>5 Min.</td>
<td>8) Rinse in Distilled Water</td>
</tr>
<tr>
<td>10 Min.</td>
<td>9) Desensitize</td>
</tr>
<tr>
<td>5 Sec.</td>
<td>10) Rinse in Ethyl Alcohol</td>
</tr>
<tr>
<td></td>
<td>11) Dry Slowly at Room Temperature</td>
</tr>
</tbody>
</table>

### BLEACH

- Ferrous Chloride: 25 grams
- Cuprous Bromide: 25 grams
- Concentrated Sulfuric Acid: 15 milliliters
- Distilled Water: 500 milliliters

### CLEARER

- Tetramethylammonium Iodide: 2 grams
- Distilled Water: 1 liter

### DESSENSITIZER

- Ethyl Alcohol: 0.9 liter
- Distilled Water: 0.1 liter
- Phenosafranine: 200 milligrams

(The process can be modified to delete steps 7 and 8 or step 9 without detrimental effects to the processed holograms)
APPENDIX VII
PROCESSING STEPS FOR
THE MARKHAM PROCESS

5 Min. 1) Develop in The Modified Developer
5 Min. 2) Rinse in Distilled Water
3) Re-expose Uniformly to White Light
   (Approximately 15 sec. to a 15-W bulb
   at 1 meter for Kodak 649-F plates and
   approximately .5 sec. to a 25-W bulb
   at 4 feet for Agfa-Gevaert 10E70 film)
5 Min. 4) Redevelop in The Modified Developer
5 Min. 5) Rinse in Distilled Water
5 Min. 6) Bleach
5 Min. 7) Rinse in Distilled Water
5 Min. 8) Clear
5 Min. 9) Rinse in Distilled Water
10 Min. 10) Desensitize
5 Sec. 11) Rinse in Ethyl Alcohol
12) Dry Slowly at Room Temperature

THE MODIFIED DEVELOPER
Kodak D-19 ..................... 1 liter
Sodium Thiosulphate .......... 0.5 gram

BLEACH
Potassium Dichromate .......... 8 grams
Concentrated Sulfuric Acid .. 10 milliliters
Distilled Water ............... 1 liter

CLEARER
Tetramethylammonium Iodide . 2 grams
Distilled Water ............... 1 liter

DESENSITIZER
Ethyl Alcohol .................. 0.9 liter
Distilled Water ............... 0.1 liter
Phenosafranine ............... 200 milligrams

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APPENDIX VIII
INFORMATION ABOUT UNUSUAL CHEMICALS
USED IN THIS PAPER

Phenosafranine (3,7-diamino-5-phenylphenazinium chloride)
M.W. 322.80 \( 3\text{-NH}_2\text{C}_6\text{H}_3\text{N:C}_6\text{H}_3\text{-7-NH}_2\text{N-5-C}_6\text{H}_5\text{Cl} \)

Phenosafranine is a red dye used mostly for biological staining

\[
\begin{align*}
\text{H}_2\text{N} & \text{N} \text{Cl} \\
\text{N} & \\
\text{N} & \\
\text{Cl} \\
\end{align*}
\]

Tetramethylammonium Iodide
M.W. 201.05 \((\text{CH}_3)_4\text{NI}\)

Tetramethylammonium is a strong electrolyte in solution

\[
\begin{align*}
\text{CH}_3 & \\
\text{N} & \text{CH}_3 \\
\text{CH}_3 & \\
\text{I} & \\
\end{align*}
\]

Pyrocatechol (Catechol), (1,2-benzenediol)
M.W. 110.11 \(\text{C}_6\text{H}_4\text{-1,2-(OH)}_2\)

Pyrocatechol provides a strong tanning action on photographic gelatin due to its high value of pH.

\[
\begin{align*}
\text{C}_6\text{H}_4 & \\
\text{OH} & \\
\text{OH} & \\
\end{align*}
\]

Xylene (1,2-dimethyl-benzene) or (1,3-dimethyl-benzene) or (1,4-dimethyl-benzene)
M.W. 106.17 \(\text{C}_6\text{H}_4(\text{CH}_3)_2\)

\[
\begin{align*}
\text{n}_D & 1.5027 \text{ (o)} \\
\text{n}_D & 1.4970 \text{ (m)} \\
\text{n}_D & 1.4954 \text{ (p)} \\
\end{align*}
\]

Xylene is used as a solvent as well as a starter for other organic compounds
### Methyl Benzoate

**M.W.** 136.15

\[ \text{M.C.} \quad \text{C}_6\text{H}_5\text{C}02\text{CH}_3 \]

\[ n_D = 1.5162 \]

Methyl Benzoate is used as a solvent, a starter for other organic compounds, and also used in perfumery.

---

### Chlorobenzene

**M.W.** 112.56

\[ \text{C}_6\text{H}_5\text{Cl} \]

\[ n_D = 1.5236 \]

Chlorobenzene is used as a solvent as well as a starter for other organic compounds.

---

### 1,2-Dibromopropane (propylene dibromide)

**M.W.** 201.90

\[ \text{CH}_3\text{CHBrCH}_2\text{Br} \]

\[ n_D = 1.5190 \]

1,2-Dibromopropane is used as a solvent as well as a starter for other organic compounds.

---

### 1,3-Dibromopropane

**M.W.** 201.90

\[ \text{Br(CH}_2)_3\text{Br} \]

\[ n_D = 1.5214 \]

1,3-Dibromopropane is used as a solvent as well as a starter for other organic compounds.

---

### Bromoethane (Ethyl Bromide)

**M.W.** 108.97

\[ \text{C}_2\text{H}_5\text{Br} \]

\[ n_D = 1.4236 \]

Bromoethane is used as a solvent as well as a starter for other organic compounds.
APPENDIX VIII (Cont.)

p-Chlorotoulene
M.W. 126.59

\[
\text{CH}_3\text{C}_6\text{H}_4\text{Cl}
\]

\[n_D = 1.5150\]

p-Chlorotoulene is used as a solvent as well as a starter for other organic compounds.
FOOTNOTES


4. Leith and Upatnieks, op. cit.

5. Cathey, op. cit.

6. ibid.


31. loc. cit., p. 61-78.
32. loc. cit., p. 78-95.
33. loc. cit., p. 95-108.
34. **loc. cit., p. 109-126.**
35. **loc. cit., p. 126-141.**
41. Colburn, Zech, and Halston, op. cit., p. 12-44.
45. Processing technique for producing phase holograms, Agfa-Gevaert, Inc., 275 North Street, Teterboro, New Jersey.
47. **loc. cit., p. 1948.**
50. *ibid.*

52. Colburn, Zech, and Balston, op. cit., p. 12-44.

53. Lamberts and Kurtz, op. cit.


55. Lamberts and Kurtz, op. cit., p. 1347.

56. Agfa-Gevaert, Inc., 275 North Street, Teterboro, New Jersey.


63. McMahon and Maloney, op. cit.

64. McMahon and Franklin, op. cit., p. 1929.

65. Upatnieks and Leonard, op. cit., p. 86.

66. McMahon and Maloney, op. cit.

67. loc. cit., p. 1367.


73. loc. cit., p. 2198.


75. Processing technique for producing phase holograms, Agfa-Gevaert, Inc., 275 North Street, Teterboro, New Jersey.


79. Type No. SEC-48, AB26, Serial No. 201312, Bendix Corporation, Pioneer Central Division, Davenport, Iowa.


82. Colburn, Zech, and Ralston, op. cit., p. 16.

83. Latta, op. cit., p. 2413.

84. Lamberts and Kurtz, op. cit., p. 1343.


90. loc. cit., p. 146. Catalog chemical No. 317, Price: 500 g - $5.45; 3 kg. - $18.10.

91. loc. cit., p. 57, Catalog chemical No. 70, Price: 1 kg. - $4.30; 4 kg. - $10.40, 5 gal. - $23.45.

92. loc. cit., p. 42, Catalog chemical No. 114, Price: 250 g - $9.00; 1 kg. - $25.55.

93. loc. cit., p. 64, Catalog chemical No. 74, Price: 500 g - $4.75; 4 kg. - $21.15.

94. loc. cit., p. 77, Catalog chemical No. 1277, Price: 100 g - $10.15; 500 g - $31.95.

95. loc. cit., Catalog chemical No. 261, Price: 100 g - $8.75; 250 g - $17.55.
BIBLIOGRAPHY

Books:


Periodicals:


114
Periodicals (Cont.):


Periodicals (Cont.):


117

Periodicals (Cont.):


Pamphlets:


Bulletin: