# Quantitative measurement of holographic image quality using Adobe Photoshop

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**Abstract**. Measurement of the characteristics of image holograms in regards to diffraction efficiency and signal to noise ratio are demonstrated, using readily available digital cameras and image editing software. Illustrations and case studies, using currently available holographic recording materials, are presented.

## 1. Introduction

While working at an embossed hologram company over a decade ago, it was recognized that there was a need to evaluate the brightness of different generations of holographic images throughout the various stages of the process. Machine vision consultants were called in, quotes were quoted, but nothing happened. But it would have been a great addition to the ISO 9000 paperwork.

Thanks to the take over of digital photography, instead of using specialty machines or software, image analysis tools available in Adobe Photoshop and other bitmap image-editing programs can be utilized to give relative readings of diffraction efficiency and with proper calibration absolute readings.

A methodology of evaluating brightness and signal to noise ratios using readily available contemporary digital photography equipment is presented, and examples of case studies of the evaluation of reflection holograms recorded on a variety of contemporary materials is presented.

## 2. Prior art

Measuring the brightness of the elemental hologram, recorded by interfering two beams, is not that difficult. In this set up an undiverged laser beam impinges on the grating, which is tilted in it holder until the dimmest zero order and brightest first order appear at the Bragg Angle.

A measurement of efficiency could be calculated by dividing the intensity of the extinguished reference beam (zero order) by the incident intensity and subtracting that from 100%, assuming that all the rest of the light is diffracted into inverse and higher orders. This is more expedient than chasing down all the rest of the diffracted orders.

However this calculation is not entirely accurate, as interrogation in this manner of two samples had the same amount of zero-order extinction, but the power delivered into the first orders are way off. Sphere-S GEO-3 and Harman Technology Holo FX red-sensitive plates exposed to Helium-Neon 633 nm beams with 30 degrees were processed in a variety of manners and the pick of the litter were selected. They both extinguished the zero order down to 1.2 mW from a 6.2 mW undiverged beam the set up depicted. Measuring the + 1$^{st}$ order beam (which was maximized when the 0$^{th}$ was minimized) yielded 3.8 mW from the GEO-3, but only 2.4 from the Harman. It is not the diffracted light that depletes the straight through beam, but a significant amount of scatter in the higher speed and noisier Harman plates.

This concept could be applied to reflection holograms processed to replay at the same wavelength as the recording laser's. The zero order depletion could be measured by placing a detector in the shadows formed by the different exposure quadrants in figure 1, although it too can be fooled by light not diffracted but scattered. In the past it has been used by some manufacturers of photopolymers which gave quite optimistic readings.

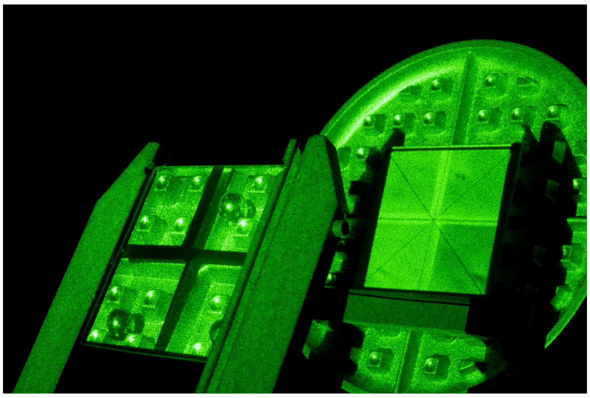

**Figure 1.** Shadow due to reconstruction depleting zero order beam.

These type of direct power measurements are fine for gratings but not for pictorial holographic images. A method of measuring the intensity of each point of an image would require a multitude of tiny power meters. If a holographic image were photographed, the resulting density changes in photographic film could be measured to form a map of intensity of the image.

The concept of photographing holographic images was implemented as early as 1980 by Joly and Vanhorebeek in their investigation of development effects in white light reflection holography.[1] They photographed the image of a USAF resolution target they had recorded on 8E56HD plates, and measured the density of the bright and clear bars on the resultant negative on Agfa Scientia 23D56 film. Knowing the d-log e curve of the film, the relative brightness and signal to noise of the exposure and developer combinations and permutations can be deduced by comparing density measurements of the similar points, having made certain to standardize lighting of the hologram and processing of the photographic recording film.

The subject of this paper is to use a similar technique using digital photography. The sensor in the image plane of the lens is filled with millions of tiny light meters. Making sense of their signals requires some preliminary calibration of the equipment and software.

## 3. Equipment requirements

### 3.1. Camera and lens

A high quality digital Single Lens Reflex (dSLR) was used for these demonstrations, a Nikon D3X. Most any "prosumer" (a contraction of professional/consumer) camera could be implemented as long as it can be used in a manual mode. The camera was set to its lowest ISO rating, 200, to minimize any amplifier noise. White balance was set to 2856 K to match the replay light. Shooting in the raw file format is essential.

The lens was a 60 mm f/2.8 Micro- Nikkor macro or close up lens, a type of lens recommended for holographic analysis, since most images are usually quite small. The samples in this study are around 65 mm square. A standard focus distance should be adopted for consistency, as magnification affects f/number. This lens not only has focus distance in metric and American units, but also the magnification ratio on its barrel, and it is set to 1:3 when photographing these specimens.

Since the lens is set to a fixed reproduction ratio, the camera is raised and lowered by the elevator on a sturdy tripod until the image is in focus. A remote release eliminates camera shake when initiating exposure.

Exposures were made with the lens set to f/5.6 in all cases. This is in part because of the conventional photographic wisdom that a lens is at its sharpest at 2 or 3 stops from its largest opening, plus it has enough depth of field for all of the depth of the standard object to be in focus, and doesn't make large speckle when photographing under laser illumination.

The camera's internal meter operating mode is then set to aperture priority, and it decides what would be the appropriate shutter speed for optimum exposure.

### 3.2. Computers

Most contemporary computers have enough processing speed to perform image editing. But the files to be evaluated, especially those of the full format or FX sensor type (6048 by 4032 pixels, > 12 Megapixels), will be huge. For instance, the raw NEF (Nikon Electronic File) weighs in at 20.0 Mb, the jpg that the camera processed along with the raw is 8.65 Mb, while the TIFF used in the evaluation step that Lightroom processed from the NEF is a whopping 69.7 Mb! Lots of hard drive space, plus some external hard drives, and loaded to the gills with RAM would not be a bad operating mode. An Apple iMac did most of the drudgery for these evaluations.

### 3.3. Software

Most bitmap, or Paint style programs usually provide a pixel sampling tool which reads out intensities in values of red, green and blue. Since Adobe Photoshop in its variety of incarnations is ubiquitous, the technique is illustrated using this program.

In addition to Adobe Photoshop, Adobe Lightroom would be a welcome addition to the holographic assessor's desktop as this image database software's keywording feature can organize holograms based on the recording material, wavelength, etc. It can also batch process many image files simultaneously, exporting the camera's native raw format as TIFF's.

3.3.1. *File Formats*. The images should be shot in the camera raw file format, not the jpg option to eliminate any compression artifacts. The raw information should be exported same pixel size to the clunky but accurate TIFF format files, so there is nothing lost in translation from the camera specific raw file to something all machines can understand. As the files will be quite large, especially for the FX or full-format chip, it would be OK to use LZW compression as it is not lossy, it, but steer clear of the JPG option. Don't forget that the advantage of compressed files is that they occupy smaller disc area, but it may take longer to open thanks to the de-compressing operation.

Here is where Lightroom really shines, being able to open a batch of raw files and exporting them as TIFF's, ready to be read by Photoshop for evaluation. Photoshop can open raw files, but only one at a time.

Working with files resized to take up smaller disk space may give erroneous readings due to the sampling and averaging of the resizing process. A smaller DX sensor might speed up the work flow compared to the full format FX and still deliver enough information for quality readings.

### 3.4. Holographic test object

To illustrate this evaluation technique single beam reflection holograms were recorded of the tried and true standard object, which is an antique waffle iron mold sprayed with Krylon brand #1401 Bright Silver spray paint. This paint uses aluminum flakes for its pigment, which in addition to being highly reflective, preserves polarization vectors, very important in forming he highest contrast fringes.

The waffle iron is a not too deep object, with a homogenous background. A series of 4 exposures is typically made on one 65 mm square plate with each quadrant having an identical scene. Three ball bearings support the holographic plate so that it doesn't rock. Plus when viewed pseudoscopically it looks like the waffle itself!

## 4. Calibration

The eyedropper tool in Photoshop reads out the light intensity that a pixel in the camera saw on a scale from 0 to 255. To get a feel for what do those numbers represent, a Kodak Gray Card was photographed alongside a white piece of paper and a black velvet cloth to determine the dynamic range of the camera. The card was photographed starting at about 5 stops brighter than the built-n meter's recommendation to 5 stops under, shortening each exposure by 1/3 of a stop, which is the finest division that the camera and lens combination allowed. At the extremes of exposure the gray card appeared as bright as the paper on the overexposed side and as dark as the velvet on the underexposed end. The grey card's value went from the minimum of 0 to the maximum of 255 over 21 third-stops, meaning the dynamic range of the sensor is 7 full stops, or $2^7$ or 128.

Table 1 shows the data compiled for the digital characteristic curve for this particular Nikon D-3X with the 60 mm f/2.8 Micro-Nikkor. It compares exposure versus the Photoshop numbers. Each consecutive exposure value differs by 1/3 stop, so 3 exposures values are one full stop, for instance going from value 4 to 7 means the light intensity at the film plane has been doubled.

**Table 1.** Eyedropper values for each exposure.

| Exposure # | Red Value | Green Value | Blue Value |
|---|---|---|---|
| 1 | 0 | 0 | 0 |
| 2 | 9 | 9 | 9 |
| 3 | 23 | 23 | 24 |
| 4 | 30 | 30 | 32 |
| 5 | 40 | 39 | 41 |
| 6 | 52 | 50 | 53 |
| 7 | 63 | 61 | 65 |
| 8 | 75 | 73 | 77 |
| 9 | 87 | 86 | 90 |
| 10 | 103 | 101 | 106 |
| 11 | 121 | 119 | 125 |
| 12 | 140 | 137 | 143 |
| 13 | 159 | 157 | 162 |
| 14 | 178 | 175 | 180 |
| 15 | 195 | 192 | 197 |
| 16 | 209 | 206 | 211 |
| 17 | 223 | 220 | 225 |
| 18 | 235 | 232 | 236 |

| | | | |
|---|---|---|---|
| 19 | 244 | 242 | 245 |
| 20 | 251 | 250 | 252 |
| 21 | 255 | 255 | 255 |

EV 11 looks like the center value, with the grey card weighing in closely at the median values of 128 for RGB.

Figure 1 is the graph of the data. The curve is not as straight of a line as would be anticipated; it has a toe and shoulder not unlike silver halide based photographic film. Its dynamic range is not as wide as that of film.

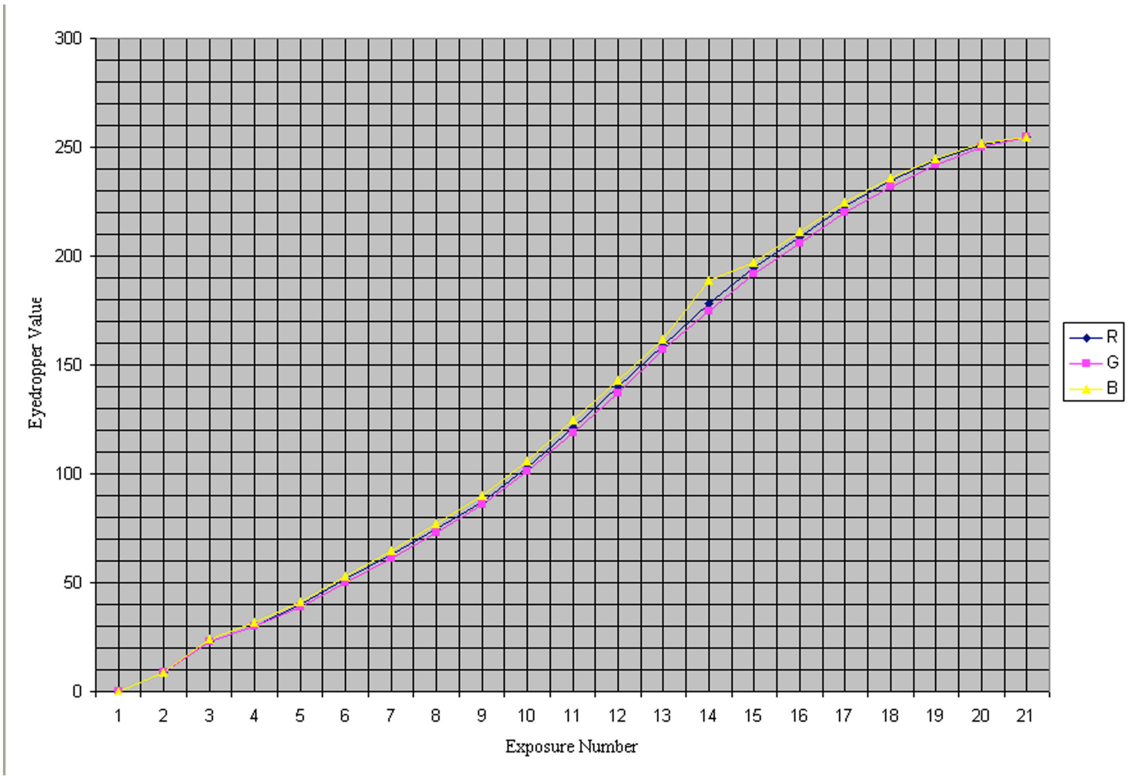


**Figure 2.** Characteristic curve of Nikon D3X.

It can be deduced from this data is that for every 1/3 stop of exposure, the RGB values change by 19 in the linear part of the curve. This is the Rosetta Stone for interpreting the relative brightness of image areas. 57 eyedropper units are equivalent to doubling or halving the light intensity in the linear part of the curve.

## 5. Set up

Repeatability of the set up is essential to be able to compare holograms made days or even years apart. Replay light distance and angle should match that recording reference beam. To do so most accurately, the shadow of a nail gnomon in a piece of cardboard placed in the plateholder can be traced, and then placed in the white light replay beam, whose tilt is finagled until the shadow at this stage matches that of the recording phase. Manipulation is made easier if the hologram lies flat on a table.

For unpainted holograms, a very dead black background to lay them on is necessary. Black velour attached to cardboard can be rendered photographically almost absolutely dead black when the calibrating gray card is in mid-scale. However the little bristles can trap not only light but dirt, which will be apparent in the photograph of some of the samples.

The camera points downward and sights directly along the normal of the hologram. Care should be taken to prevent direct light from impinging directly on the camera lighting it up, so that the camera does not see a reflection of itself.

The camera lens was set to a certain distance, make it up if you have to, For this ongoing experiment, every time a new batch of holograms were photographed, the macro lens was set to a reproduction ratio of 1:3; the image height and width are one third of the object's. The camera itself was raised up and down to focus at the standardized reproduction ratio.

For white light reconstruction, the camera's color balance needs to match that of the light source. The typical halogen lamps for replay are not necessarily 3200K like that of photographic studio floods associated with the light bulb default icon. Custom white balance might be in order, or set the camera to the 2856 typical color temp.

For consistent results, a calibration target in the form of the Kodak Neutral Gray Test Card was positioned where the holograms were to be photographed to be metered by the camera. In a suspenders and belt approach, an incident light meter, a Sekonic Studio Deluxe, was also placed in the hologram's position to correlate the exposure. Surprisingly they almost always agreed!

The gray card was always included beside the hologram in the photograph. It can then be sampled in the evaluation stage to assure consistency between different shooting sessions.

## 6. Methodology

Once the hologram's TIFF file is opened, the eyedropper tool needs to be engaged. Its Info Palette should be open, and its sampling size should be set appropriate to the task at hand, never single point as that would give some touchy readings, usually run with an average of many, no smaller than the 5 by 5 Sample Size. This will alleviate errors caused by dust and dirt and laser speckle.

Also visible in the Info Palette are the X and Y coordinates of the cursor, which indicates exactly which pixels are being interrogated. Very accurate relative readings can be made of exactly the same object point in a variety of holograms, especially if the Rulers' Units are set to pixels. Guides dragged out of the Rulers can provide landmarks for exact same sample locations.

### 6.1. Example 1: Brightness versus exposure

The Color Sampler Tool, a recent addition to PhotoShop, is a quartet of Eyedroppers. It is found in the same fly-out as the Eyedropper. Samples can be taken of 4 points, and their readings are displayed simultaneously. Figure 2 shows the readings for 4 similar object points in four differently exposed quadrants on a test strip. The hologram was shot on Sphere-S GEO-3 emulsion, with exposures of 800, 1600, and 3200 and 6400 microJoules per square centimeter. In photographic parlance, the exposures increased one stop in each fourth.

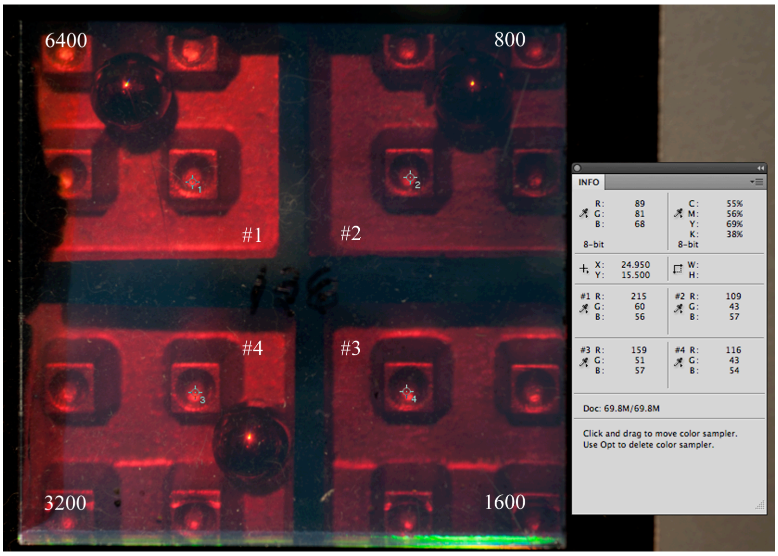

**Figure 3.** RGB values of varying exposures

Correspondence between Color Sampler Info Palette placement is by position; #1 corresponds to 6400, #2 to 800, #3 to 3200 and #4 to 1600. By finding the difference between any two exposures' Eyedropper numbers, and dividing by the correlation coefficient of 19 points per 1/3 stop, we can see increase of brightness with each stop of exposure. The increase in red from 800 going to 1600 is 116 - 109 = 7, about a sixth of a stop; then an increase of 43, ¾ of a stop, almost twice as bright, then the last jump of 56, a full stop, twice as bright as its predecessor, and four times as bright as the first exposure. The increasing differences in brightness shows that the material is working just over threshold, on the toe of its characteristic curve.

The blue reading is constant, which is good. Film scatter noise is dominated by the blue end of the spectrum, and these numbers show that it is not increasing with exposure. The green is increasing, along with the red, as there is a green component to the bandwidth of the reconstruction under white light, which can be seen peaking through in the highlight of the ball bearing support in the upper left quadrant.

6.2. Example 2: Signal to noise calculations

In this screen grab, the brightest and noisiest areas are sampled on a pair of Ultimate U08 plates. The one on the left received 800 uJ/cm^2 of exposure at 532 nm, while the one on the right received twice as much, seriously overexposing it. Both were developed simultaneously for the recommended time in the Ultimate Developer and bleached in the Ultimate Bleach.


**Figure 4.** Signal to noise study.

The Color Sampled Readings are as follows:

- #1 (Noise in 800): R = 19, G = 44, B = 23.
- #2 (Noise in 1600): R = 43, G = 73, B = 52.
- #1 (Signal in 800): R = 62, G = 200, B = 0.
- #1 (Signal in 1600): R = 74, G = 170, B = 23.

The section of the image sampled for the noise was in the shadow of a ball bearing that supports the holographic plate during exposure. Ideally there should be no light seen from that part of the image, but there is enough light from other parts of the object slightly illuminating the umbra that there is an image background on top of the noise background caused by intermodulation and scatter due to the material and its processing.

The total luminosity of the noise is the sum of the RGB readings. For the 800 exposure, this is 19 + 44 + 23 = 86, for 1600 it's 43 + 73 + 52 = 168. The ratio of these two sums are almost doubled, but the relative brightness is found by subtracting these two numbers, 168 – 86 = 82, then dividing 82 by 57, the number found in the characteristic curve of the camera which is equal to one full stop of brightness change, to find the amount of stops difference in brightness, 82/57 = 1.44, and to find how many times brighter need to take 2 to the 1.44 power using the y^x key on the calculator, which equals 2.7 time brighter.

Finding the signal to noise ratio is done in a similar manner. The total luminosity of the bright area of the 800 is 62 + 200 = 262. This is actually a signal plus noise reading; its noise reading is 86 from the above. The difference of these two is 176 which is the signal reading; dividing 176 by 57 = 3.0, 2^3 = 8, so the signal to noise ratio of this sample is 8 to 1.

The noisier one has a signal plus noise to noise difference of 267 – 168 = 99, which is divided by 57 = 1.7, 2^1.7 = 3.2 for its signal to noise ratio.

Usually a noisier hologram appears brighter than a more contrasty, low noise one, and theswe numbers seem to bear this out. The lower exposure's total luminosity is 262 versus the higher one's 267; slightly more light arrives at the camera or the observer's eyes. But the amount of signal, as was just calculated, is 176 units on the 800 versus 99 on the 1600, a difference of 77, about 1 1/3 stops, or 2 ½ times as bright! The higher noise fills in the shadow areas, making the image appear "underwater".

6.3. Example 3: Bandwidth and shrinkage

This method can be used for checking the accuracy of the replay wavelength and its bandwidth. A baseline reading of the laser wavelength is taken, and the replay is compared to it. A gray card was photographed under spatially filtered 532 nm laser light, with exposures bracketed above and below that recommended by the camera's built-in meter. Surprisingly the eyedropper's values were not only reading green content but also some blue, even though the illumination was monochromatic! This is because the Bayer filter on top of the digital sensor, which analyzes the RGB content of the scene, acts like the human eye, whose RGB cones have overlapping sensitivities so that different hues of green for instance, can be discriminated.

Blue and green values for 3 exposures bracketed by 1/3rd stops:

- G = 165 185 202
- B = 85 95 105
- B/G = .52 .51 .52

From this calibration is can be inferred that 532 nm laser light is represented by 2 parts G and 1 part B. This is our baseline in determining color truthfulness to the laser lambda.

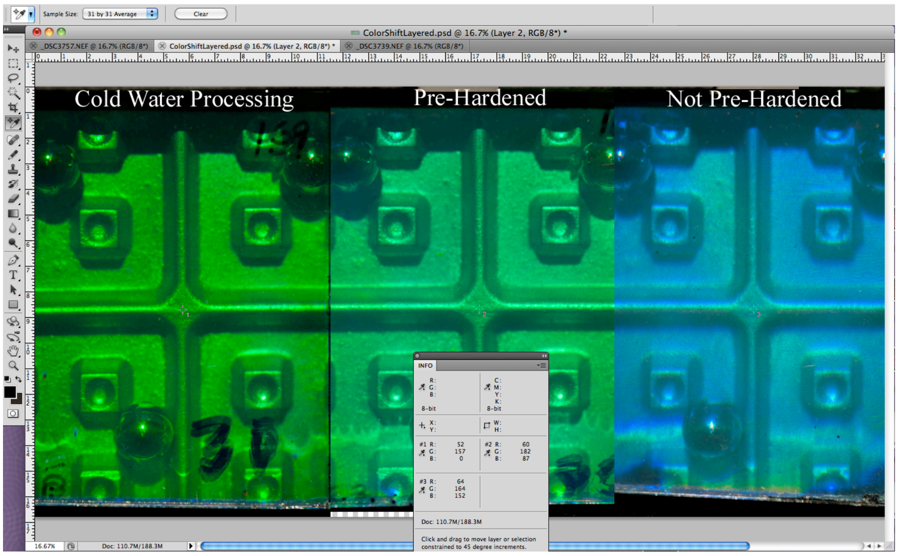


**Figure 5.** Bandwidth measurement of 3 processing procedures

Here is a comparison of some Sphere-S GEO-3 plates. All three were exposed for 6400 microJoules per square centimeter at 532 nm. The one on the left was processed in cold water, 15C, the middle one was dunked in formaldehyde pre-hardener and processed at room temperature, 20C, and the one on the right was processed simultaneously with the middle except it was not pre-hardened. (See Appendix for more details.) The cross piece in the middle of the object was sampled.

- Cold process: R = 52, G = 157, B = 0.
- Pre-hardened: R = 60, G = 182, B = 87.
- Not pre-hardened: R = 64, G = 164, B = 152.

All 3 of the green readings are quite similar. But the cold process plate, although not giving the same ratio of G to B under reconstruction with white light, has the narrowest bandwidth, with no B value. This is also the least noisy. The pre-hardened plate is noisier with a wider bandwidth visually, and the numbers bear that out. Obviously the hardener is a necessary evil, as without it there is considerable shrinkage to the shorter wavelength and the replay bandwidth is wider.

6.4. Example 4: Absolute efficiency

If the eyedroppered values of the holographic image were identical to that of the object, then the hologram would be 100% efficient, if we subscribe to the basic tenet that the hologram is an exact optical double of the object.

The Standard Object was photographed with 458 nm illumination. This same exposure was used to photograph two samples of Slavich PFG-03C exposed in that same location, one for 12.8 milliJoules per square centimeter, the other for 25.6. Both were processed in the same cold regimen as the GEO-3. They reconstructed quite brightly when replaced on the object, so well that real-time interference fringes could be observed. A piece of black velvet was placed under the holograms so that this effect could not be seen when photographing them.

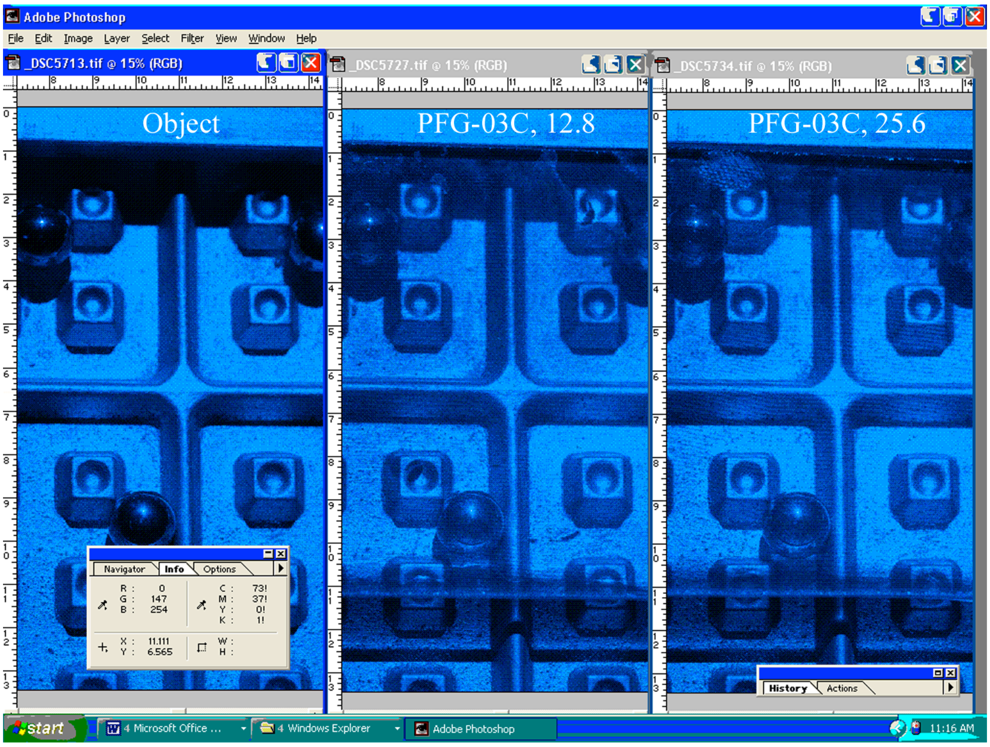


**Figure 6.** Absolute efficiency.

Readings at the crossbar in the center of the iron were:

- Object: R = 0, G = 150, B = 254.
- 12.8: R = 0, G = 138, B = 251.
- 25.6: R = 0, G = 150, B = 254.

It looks like 25.6 has achieved 100% efficiency! However the hologram readings contain signal plus noise, so a shadow area under a ball bearing was sampled for each scene to get the noise reading. There are some values in the object's reading, as this background is caused by diffuse reflections from other object points filling in the shadows. The hologram should record this information, but it does add its own noise to that.

- Object: R = 0, G = 19, B = 45.
- 12.8: R = 0, G = 29, B = 86.
- 25.6: R = 0, G = 29, B = 86

The noise of both holograms added 10 units of G and 41 units of B to the background, so subtracting that out from the preliminary readings gives:

- Object: R = 0, G = 150, B = 254.
- 12.8: R = 0, G = 128, B = 210.
- 25.6: R = 0, G = 140, B = 213.

Now the difference between the brighter hologram and the object is 254 -213 = 41, 41/57 = .7 of a stop, 2^.7 = 1.6, meaning that the object is 1.6 times as bright, or the hologram is 60% efficient. Which is not too shabby considering the recording wavelength!

## 7. Acknowledgements

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**References**

[1] Joly l and Vanhorebeek R 1980 Development Effects in white light reflection holography *Photographic Science and Engineering*.**24(2)** 108-13

[2] nlutie.com/ewesly for more information on cold water processing and trials of holographic materials.